Report of the Eminent Panel on Seal Management

Panel Members: Dr. Ian McLaren, Chair
Dr. Solange Brault
Professor John Harwood
Mr. David Vardy

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Executive Summary

The panel was appointed by the Minister of Fisheries and Oceans "to provide advice on the best strategies for management of seal populations in Atlantic Canada, including a balanced and objective view of scientific information on seal populations and predator-prey relationships and how this information can contribute to development of management strategies." The panel was asked to provide:

- an assessment of the available scientific information on dynamics of seal populations and the ecosystems of which they are part;
- if an optimum size of the seal population can be identified, advice on management strategies to attain such an optimum population size;
- advice on directions for improving scientific knowledge of dynamics of seal populations and the ecosystems of which they are part, to ensure that the scientific basis for seal management is sound;
- advice on whether and to what extent seal exclusion zones or experimental culls would provide protection to vulnerable local populations of commercial fishes;
- an assessment of all sources of harvest mortality on Atlantic seal stocks including but not restricted to harvests inside and outside Canada and mortality of animals struck and lost;
- advice on the most appropriate strategic directions for management of seal populations in the context of the above considerations and analyses and in particular for the next five years.

The panel advertised nationally in both official languages and held a number of consultations in Atlantic Canada. It commissioned re-analyses of data on hooded seal diet and harp seal pup production.

Seal abundance and mortality

The harp seal population increased substantially during the 1980s and early 1990s because of reduced harvest rates. Higher levels of harvest by Canada and Greenland in the mid-1990s appear to have stabilised the population, at least temporarily, at around 5.2 million individuals. The procedure used to estimate total population size and replacement yield (the level of harvest that will maintain the population at its current size) now takes account of the size of the Greenland harvest, and estimates of the numbers of seals killed by hunters but not landed and of the numbers bycaught in fishing gear. This has substantially improved the quality of the estimates of population size and replacement yield. The calculated replacement yield is used as the basis for the Total Allowable Catch (TAC) of harp seals in Canadian waters. Pregnancy rates have decreased since the 1980s, but the panel does not believe that the seal population is near the carrying capacity of the marine environment, as some stakeholders have suggested.

There are no reliable estimates of the current size of the hooded seal population in the northwest Atlantic. The last comprehensive surveys were in 1990/1991, and there is an urgent need for a new survey. The annual harvest of this species in Atlantic Canada has varied from less than 100 to more than 20,000 since the introduction of a ban on the sale of blueback pup skins in 1993.

Grey seal pup production has been increasing at ~13% per year on Sable Island. The rate of increase in the Gulf of St. Lawrence is less certain, although clearly smaller. There has been little hunting mortality since the cessation of the bounty in 1990.

Economics of the seal hunt

Although DFO sets an annual TAC for harp and hooded seals, the actual catch is determined by market forces, weather conditions, and levels of government subsidy. Harp seal catches were well below the TAC from 1983 until 1996, when they rose to ~240,000. The TAC of 275,000 was slightly exceeded in 1998, but catches declined to ~91,000 in 2000. The 2001 take was ~210,000. The TAC for hooded seals was increased to 10,000 in 1998 and was taken in full in that year, but relatively few hooded seals were taken in 1999 and 2000.

Estimates of the landed value of the seal catch in 1998 range from $5.6M to $8.75M. Traditionally, pelts have been the largest component of product value but production of oil for human consumption has grown substantially in recent years. The sealing industry believes that there is large potential for increased sales of high-grade pelts and seal oil, especially if U.S. trade barriers can be overcome.

The panel found it difficult to determine current and historical levels of direct and indirect subsidies to the industry and their effects. One study estimated that the added value of the industry in 1996 was only 0.06% of the gross domestic product of Newfoundland, after costs and subsidies had been subtracted. Meat subsidies during the 1990s contributed to high harvests, but were phased out in 1999. Subsidies provided to the Canadian sealing industry must be viewed in the context of the levels of subsidy provided to other fisheries in Canada, and to sealers in Greenland and Norway.

Prey consumption by seals and impacts on fish stocks

Estimates of the amounts of some commercial fish species (particularly northern cod, redfish, Greenland halibut and American plaice) consumed by seals in many NAFO Divisions are large in comparison to current fisheries catches. Seals also consume large quantities of capelin, which is an important prey for many of these commercial species. However, the current estimates are imprecise, and may be biased. In the case of harp and hooded seals, this is because most of the diet samples have been collected in inshore waters, whereas both species spend most of their time feeding offshore.

The impact of the calculated removals on the current size of commercial fish stocks is difficult to assess. However, the estimated consumption of Atlantic cod by seals in Divisions 4RS3Pn and 2J3KL is particularly large, and this may be contributing to the apparently high levels of mortality experienced by those stocks. In some local areas, such as river mouths, for salmon, and inlets on the east coast of Newfoundland, for cod, predation by seals may be a particularly important source of mortality.

The role of seal predation in the apparent failure of some severely depleted fish stocks is unclear. However, it should be recognized that many of these stocks will probably take a long time to recover to fully exploitable levels, even if all seal predation is removed. The situation is further complicated by the environmental changes that have occurred since the late 1980s, and the associated shifts in the distribution of important prey species such as capelin and arctic cod. The proportion of northern cod in the diet of harp seals appears to have remained relatively constant since the 1980s, despite the massive reduction in cod abundance. This has led some stakeholders to conclude that seals could be holding cod in a "predator pit", but this conclusion is based on diet samples from inshore waters around Newfoundland where recent changes in cod abundance may have been much less dramatic than those that occurred offshore.

One panel member (David Vardy) believes that the balance of evidence is sufficient to conclude that "Seal predation poses a serious threat to the recovery of northern cod and other important cod stocks in Atlantic Canada and to the rebuilding of these stocks to their historical levels." The other panel members believe that the available evidence does not justify such a strong conclusion.

The impacts of seals on the salmon farming industry in New Brunswick, and probably elsewhere, have become broadly tolerable as a result of better anti-predator nets and adequate insurance, although individual growers still suffer large losses.

"Optimum" size of the seal population and management objectives

Any change in abundance of a seal species will affect other species in the ecosystem, and these affects will have consequences for a wide range of stakeholders. For example, a reduction in harp seal numbers will certainly reduce the TAC for the sealing industry, and will probably result in an increase in cod stocks, at least in the short term. The increase in cod abundance might then result in increased TACs for cod. In the longer term, an increase in cod abundance could result in reduced TACs for the shrimp and crab industries. Furthermore, there are large uncertainties associated with the estimates of the quantities of cod, and other economically important groundfishes, consumed by seals and with any predictions about the way in which fish stocks may respond to reduced seal predation.

If what economists call "utility values" can be attached to the different outcomes that may result from a change in seal numbers, then it may be possible to identify an optimum size for a seal population. The panel's terms of reference do not provide any guidance on these values, and the panel was therefore unable to identify a single optimum size for any of the seal populations in Atlantic Canada. It could not, therefore, advise on "management strategies to attain such an optimum population size."

Scientists have been trying to find ways to cope with uncertainty in the management of fisheries for some time, and Canadian scientists have been in the forefront of this work. But seal management in Canada has not taken advantage of these developments. The most promising approach involves defining a set of control rules that are used to set the TAC and the way in which it can be taken, and a set of Reference Points that are used to monitor the effectiveness of management. In particular, the probability that the exploited population will fall below a Limit Reference Point must be kept as low as possible. The panel strongly recommends that a management approach of this kind is applied to seal populations in Atlantic Canada.

In order to illustrate how this management approach could be used and how an optimum size for the seal population might be identified, the panel evaluated the likely costs and benefits that sealers, groundfish fisheries in Divisions 2J3KL, and DFO might experience under five different management scenarios for the harp seal population. There are winners and losers under each of the scenarios, and the uncertainty associated with some of the benefits is often very much greater than that associated with some of the costs. Any decision about which stakeholder group should have the greatest chance of benefiting from seal management and which should lose out must be based on a socioeconomic analysis rather than a purely biological one.

1. "Status quo". The TAC is set on the basis of replacement yield, but may not be taken in full each year because of market forces and ice conditions. It should never be exceeded. Because of this, there is a greater than 50% probability that the population, and therefore overall fish consumption, will increase. Sealers will benefit from a relatively stable TAC in the short term, and a probable rise in the TAC in the longer term. Seal predation on groundfishes and capelin is likely to increase.

2. "Market forces". Under this scenario, a high utility value is attached to benefits to the sealing industry. That industry is allowed to set the TAC, but it may be reduced (possibly to zero) by DFO if the probability that the seal population will fall below the Limit Reference Point is judged to be too high. The size of the TAC set by the industry may be higher or lower than that set under the "status quo" scenario, depending on markets for seal products and how the industry discounts future revenues. The effects of this management on capelin and groundfishes consumption are therefore unpredictable.

3. "US Marine Mammal Protection Act". The US Marine Mammal Protection Act defines a specific Limit Reference Point for all marine mammal populations and provides a formula to calculate a TAC that ensures there is a high probability the population remains above this Reference Point. If this approach is applied to the northwest Atlantic harp seal population the Canadian TAC will be substantially lower than under the "status quo" scenario, unless the size of the Greenland catch is also reduced. Seal numbers would be expected to increase by around 3% per year. After 10 years of management under this scenario, annual consumption of northern cod by seals is calculated to increase by 11,000 tonnes (of which approximately half might be fish of commercial size) and consumption of capelin by 155,000 tonnes. However, there are large uncertainties associated with these calculated values

4. "Stabilize fish consumption". This scenario is a modification of the "status quo" scenario. If the TAC is not taken in full, DFO pays sealers to kill additional seals to ensure that the entire replacement yield is taken each year. The short-term benefits to the sealing industry are the same as under the "status quo" scenario, but TACs are not expected to rise in the longer term. This is because there is an equal probability that seal numbers, and fish consumption, will increase or decrease.

5. "Reduce fish consumption". Under this scenarios, potential benefits to groundfish fisheries are given a high utility value. The objective of management is to reduce consumption of certain fish species in Divisions 2J3KL by a specified amount. For example, the panel calculated that the annual consumption of northern cod might be reduced by 3,000 to 4,000 tonnes after five years if the Canadian seal TAC was increased by 150,000 or if 75,000 females were killed each year in addition to the existing TAC. A similar effect could be achieved by sterilizing 150,000 females each year. Consumption of other groundfish species would also be reduced. However, the panel was

unable to estimate how this reduced consumption might translate into revised TACs for groundfish stocks. Although there may be short-term benefits to the sealing industry under this scenario if the reduction is achieved through an increased TAC, even this will depend on the nature of the demand for seal products. Once the desired reduction has been achieved, the seal TAC will have to be reduced and sealers' incomes will probably fall. If the reduction is achieved by killing or sterilizing females, then DFO will have to bear the cost of this.

6. "Seal exclusion zones." The establishment of exclusion zones to protect overwintering aggregations of cod from harp seals is probably feasible only in fjord-like environments like Smith Sound in eastern Newfoundland. The panel recommends that any attempt to establish such zones should take the form of a scientifically designed trial. Such trials are unlikely to affect seal TACs but will involve additional costs to DFO. The possibility of using acoustic devices to scare seals away from these zones should also be explored, although account should be taken of their potential effect on other wildlife such as porpoises.

Until a new estimate of pup production and more information on diet and movements is available, the costs and benefits of management scenarios for hooded seals like those described above for harp seals cannot be evaluated. The current ban on the taking of blueback seals provides much greater protection for hooded seals than the prohibition on taking whitecoated seals does for harp seals. The panel believes that, if the aim of management is to protect "baby" hooded seals (i.e. those still in their mother's care), this can be achieved without resorting to a complete ban on the hunting of bluebacks by setting an appropriate opening date for the hooded seal hunt. This would have benefits for the sealing industry.

The above management scenarios could also be applied to grey seals on the Scotian Shelf and in the Gulf. However, any calculations of expected changes in consumption of fish will involve even greater uncertainties than those applying to the calculations for harp seals. The "status quo" and "market forces" scenarios are likely to result in an increase in fish consumption because of the limited current demand for grey seal products. The two "fish consumption" scenarios could only be implemented if Sable Island was opened to a commercial pup hunt, or DFO carried out a contraception programme there. Although it has been suggested that grey seal exclusion zones could be established in Sydney Bight or St. Georges Bay, Cape Breton, the panel is skeptical about the potential benefits of this, because any seals that are killed are likely to be replaced quickly by immigrants from surrounding areas.

Recommendations for research and management

Research

- Funding for seal science in general should be increased and made less dependent on short-term, application-driven sources
- All hooded seal breeding aggregations in the northwest Atlantic should be surveyed from the air as soon as possible. All available information on age structure and reproductive status should be analysed to provide improved estimates of survival and pregnancy rates. These data should then be used to recalculate the TAC for this stock.
- Existing estimates of grey seal pup production and population size should be published as

soon as possible.

- DFO should accelerate research on all aspects of high mortalities of groundfish stocks. Funds for groundfish research could be used to improve estimates of seal consumption, because this is probably a fundamental component of these mortalities. Stock assessment programs for capelin off Newfoundland and in the Gulf should be reinstated, because the abundance and availability of this species is central to an understanding of recent and future changes in the abundance of groundfish and seals.
- Existing information on the movements of satellite-tagged harp, hooded and grey seals should be published as soon as possible. More satellite-tracking of harp and hooded seals is needed to determine if their distribution has changed since the mid-1990s, and to improve the design of seal diet studies.
- Work commissioned by the panel suggests that hooded seals may be consuming large quantities of northern cod in Divisions 2J3KL. However, these results are based on very small sample sizes, particularly in offshore areas, and more samples are urgently required.
- The results of existing work on the use of fatty acid profiles to determine the diet of grey seals should be published as soon as possible.
- Existing data on seal diet should be reanalyzed to determine the most cost-effective way of reducing the large uncertainties associated with current estimates of fish consumption.

Management

- National and provincial governments should provide consistent and accurate data on their direct and indirect financial support to the sealing industry.
- Management of seals in Atlantic Canada should have explicit objectives. DFO should commission a study to develop a generic set of control rules and Reference Points that could be applied to any of the management scenarios described above.
- Canada and Greenland should cooperate in the conduct of scientific research and in the management of seal species that are common to both jurisdictions.
- The potential benefits of seal exclusion zones should be investigated in a trial involving experienced seal collectors, with appropriate levels of replication. Stomach and blubber samples should be collected from all seals that are shot, and the abundance and distribution of cod should be monitored in experimental and control areas.

1. General introduction

This final report to the federal Minister of Fisheries and Oceans is in fulfilment of the Terms of Reference (TOR) of the Panel (see **Appendix 1**). The stated TOR objectives for the Panel are: "To evaluate the current state of scientific knowledge and to provide advice on long-term strategies for management of seal populations in Atlantic Canada" and "develop a strategic harvesting plan for seal populations for the next five years." These objectives are then elaborated in the TOR as a series of deliverables.

It will be seen that there are no specific sections in the report on the first two deliverables, which call for brief descriptions of Northwest Atlantic marine waters and ecosystems and of the life histories and ecology of its seals. The Panel has concluded that those subjects are adequately dealt with in many general sources. However, many elements of the two deliverables are included in the sections **2**, **4** and **5** of this report.

The next three deliverables of the TOR involve assessment of scientific knowledge and make up a substantial part of the report:

- methods for estimating seal population abundance (section **2**);
- methods for estimating total mortality . . . and information on the impact of the hunt on seal populations (section **2**);
- knowledge of diet of seals and of the impact of seal predation on fish stocks (section **4** and **5**).

The sixth deliverable calls for assessment of "the optimum size of seal populations in terms of their interactions with other components of the ecosystem." Certainly, as we shall demonstrate, seal populations influence and are influenced by many other components of Canadian Atlantic ecosystems. However, such an optimum can only be identified in the context of management aims or policies. Since the TOR do not identify such aims or policies, the Panel explores the probable consequences of a range of management options in section **5**, which also addresses other specific management issues noted in the TOR.

Finally, the requests for advice on improving scientific understanding as a basis for management are fulfilled in a separate section **6**.

It became clear to the Panel that economic factors affect many issues of seal science and management in Atlantic Canada. Accordingly, we include in our report a review and analysis of the economics of the seal hunt (section **3**), although this is not explicitly called for in the TOR.

During its deliberations, the Panel was particularly pleased with the current transparency and availability of DFO research through the DFO publications web site. This has allowed the Panel to use very recent information and analyses on both seals and fish stocks. In addition, the Panel asked for and obtained from DFO scientists several re-analyses and extensions of existing information, for which we are grateful. Also, as sanctioned by the TOR, the Panel was able to contract expertise for two vital needs to improve scientific understanding. The first was a re-analysis to improve the precision of the estimate of the harp seal pup production from the most recent aerial survey. The second was to re-analyse available DFO information on the diets of hooded seals.

The TOR indicate that, in its Mode of Operation, "the panel will base its work primarily on review of available reports, information, and surveys," and that it "is not to conduct a broad consultation on seal harvesting in general, but… may wish to consult parties with information or an interest in this issue for information directly related to [its] objectives." These "parties" are identified as provinces, stakeholders, individuals and groups with interests in sealing policies and activities that might contribute management strategies. To that end, the Panel has held meetings with DFO and academic scientists; members of the Fisheries Resource Conservation Council; provincial, fishing industry, and sealing industry representatives; representatives of non-government organizations; and individual fishers and sealers. These contacts are summarized in **Appendix 2**. In addition, the Panel received, spontaneously or by request, numerous briefs, letters and e-mail messages concerning its mandate. In an effort to consult as widely as possible, advertisements calling for input were placed in the 18 October 2000 editions of *The Globe and Mail* and *La Presse*, the first published in English, the second in French. **Appendix 3** contains a listing by date, title and source of all written submissions; a copy of each submission was filed with this report. Although we do not refer explicitly to all of these submissions, all were considered in the preparation of this report.

Because the Panel was not convened until June 2000, we were informed that the original due date stated in the TOR, 15 October 2000, did not apply, and it was extended to the end of July 2001. The Panel therefore submits this report as the fulfilment of its mandate.

2. Current methods for estimating seal abundance and mortality

2.1 *Introduction*

Table 2.1 provides a summary of the most recent estimates of the size of seal population in Atlantic Canada and an indication of where in this section further information on the estimates can be found.

Table 2.1 Most recent estimates of the size of the population of different seal species in Atlantic Canada. 1. Stenson et al. 2000a, 2. Stenson et al. 1997a, and Hammill et al. 1992, 3. Hammill et al. 1999a, 4. Bowen et al. 1999, 5. Healey & Stenson 2000, 6. Hammill & Stenson 2000.

Species	Most recent survey	Pup production	Population size	Section
Harp seal	1999	997,900[1]	5,200,000[5]	2.2.1 2.5.1
Hooded seal	1990/91	85,100[2]	469,900 (1990)[6]	2.2.2 2.5.2
Grey seal	1996	11,757 (Gulf)[3]		2.2.3
	1997	7,426 (Gulf)[3]	173,500 (1996)[6]	2.5.3
	1997	25,200 (Sable)[4]		
Harbour seal	2000		31,900 (1996)[6]	2.7.1

Seals spend most of their time at sea, and mostly underwater. As a result, it is difficult (and usually impossible) to census the whole of a seal population directly. Instead, some more accessible but well-defined component of the population is counted. Three of the species considered by the Panel (harp seal, hooded seal and grey seal) aggregate to breed, and their pups remain on the land or ice where they are born over a number of days or weeks. The pup component of their populations has traditionally been censused. The various methods that have been used to estimate the size of this component of the population for Atlantic Canadian harp, hooded and grey seals are described in **2.2.** Although harbour seals also aggregate to breed, their pups are often born on intertidal rocks or sandbanks, so they spend some of their time in the water from birth. For this species, a different component of the population, usually the number of seals hauled out during the annual moult in July or August, must be censused. The available information on harbour seal numbers is discussed in **2.7.1**.

In order to convert the estimate of the number of pups born in a particular year, or the number of harbour seals hauled out on one day during the moult, to an estimate of total population size, additional information on the life history of the surveyed species is required. If pup counts are being used, we can estimate the size of the adult female population if we know the proportion of these females that give birth each year. The available information on this demographic parameter for harp, hooded and grey seals is described in **2.4**.

The number of subadult animals can be estimated in a number of ways. At the very least, we need to know annual survival rates from birth to first breeding. These rates will depend not only on the natural risks that young seals are exposed to, but also on how many are killed by hunters or as bycatch in fishing gear each year. The number of seals that die each year as a result of human activities can be estimated directly, and this is described in 2.3. However, natural mortality rates are more difficult to estimate directly, and the estimation of these parameters has usually been combined with the estimation of total population size. The methods used for this combined estimation process are described in 2.5.

2.2 Pup production

2.2.1 Harp seal

In the Northwest Atlantic, harp seals aggregate to breed on ice floes in the northern Gulf of St. Lawrence and off the northeast coast of Newfoundland. Attempts to survey these aggregations from the air have been made since the 1950s (reviewed briefly in Healey and Stenson 2000), but until recently it was not possible to ensure that all aggregations were surveyed or that some aggregations had not been counted twice. However, complete aerial surveys were conducted in 1990 (Stenson et al. 1993), 1994 (Stenson et al. 1996) and 1999 (Stenson et al. 2000a).

In each case, a combination of visual counts from a low-flying helicopter and counts from high-resolution aerial photographs were made. Counts were then corrected for animals missed on the photographs (by comparison with counts made on the ground, or from photographs taken with film sensitive to ultraviolet light on which the whitecoat pups show up more clearly than with conventional film). The results of the 1990 survey have also been corrected for pups that were born after the survey flights (Myers and Bowen 1989). In some years, visual counts of particular aggregations were preferred to photographic counts, in other years this preference was reversed. Johnston et al. (2000) have questioned the validity of this selection, and suggested that as a result the series of aerial survey estimates is not internally consistent. Although this is technically correct, the differences between the estimates of pup density from the direct counts and the aerial photographs are relatively small. The calculated variances for the estimates of pup production from these surveys take account of variation between the aerial transects but not of variation along the transect itself. The Panel therefore commissioned a reanalysis of the data from the 1999 survey (Stahl et al. 2001) that took account of both sources of variation. The resulting estimate of pup production was very similar to that obtained by Stenson et al. (2000), but the coefficient of variation was reduced to one quarter of the value reported by those authors. This suggests that there is systematic variation in harp seal density along the transects (which generally run from the coast offshore) and that accounting for this variation can substantially reduce the coefficient of variation of the estimates of pup production. The Panel therefore recommends that the same approach be applied to the analysis of the results of the 1990 and 1994 surveys.

Estimates of pup production for years prior to 1990 have made use of the commercial harvest. Sergeant (1975) noted that the large year-to-year variations in the number of whitecoat pups killed in the 1960s should be reflected in the age structure of the population. He suggested that, if pup production was relatively constant over a particular period, the relationship between an index of the relative survival of pups from a particular year and the number of pups killed in that year could be used to estimate the average number of pups born per year over that period. Estimates of pup production based on this Survival Index (or subtle variations of it) were used by a number of authors during the 1970s and early 1980s. However, in 1982 Cooke showed that the basic formulation of the Survival Index was inappropriate, although his results were not published in a refereed journal until 1985 (Cooke 1985). Cooke derived a more appropriate formula, and used it to estimate pup production in the periods 1958-1967, and 1968-1977. However, estimates of the Survival Index have almost always been calculated from the age structure of samples of male harp seals shot during the moult. Roff and Bowen (1986) showed that the representation of the youngest age classes in these samples varied substantially from year to year, making application of even Cooke's version of the Survival Index questionable. Older age classes are represented more consistently, but errors in age determination tend to increase with age. Since the Survival Index is calculated from the ratio of the number of animals in successive age classes, errors of this kind severely affect the reliability of the index. For these reasons, estimates of pup production derived from the Survival Index were not used for nearly 20 years. However, Winters and Miller (1998) have recently made use of a time series of population estimates for the period 1952-1976 that are based on the original Survival Index.

Data from the activities of hunters have also been used to estimate pup production by marking whitecoat pups with individually numbered tags inserted into the hind flipper and tallying the returns of these tags. Bowen and Sergeant (1983) used this technique to estimate pup production in 1978, 1979 and 1980. Roff and Bowen (1986) revised these estimates to take account of tag recoveries reported after Bowen and Sergeant completed their analysis. They also recalculated the original standard errors for these estimates, because "the previous standard errors . . . were overestimated." However, they do not explain why these values were overestimated or how the new values were calculated. A further tagging exercise in 1983 is described in Bowen and Sergeant (1985), but these results have never been published in the primary literature.

2.2.2 Hooded seal

Hooded seals also aggregate to breed in the regions used by breeding harp seals, although they are usually more widely scattered. An additional breeding aggregation is known to occur further north in Davis Strait. Complete aerial surveys of the breeding aggregations, and of more dispersed seals on the surrounding ice, off the northeast coast of Newfoundland were made in 1984 (Bowen et al. 1987) and 1990 (Stenson et al. 1997a). The 1984 survey also included the Davis Strait aggregation. Pup production in the Gulf was surveyed in 1991 (Hammill et al. 1992). No comprehensive hooded seal surveys have been made since 1990/1991. Estimates of pup production from all of the surveys were corrected for animals that were incorrectly identified as pups, for pups born after the survey, and for those born before the survey that had already left the ice.

Stenson et al. (1997a) also reviewed previous estimates of hooded seal pup production. There are a number of estimates from the 1960s and early 1970s based on the Survival Index method that cannot be considered as reliable. Estimates from 1977-1982 applied only to breeding aggregations where there was hunting and these almost certainly underestimated total pup production. Stenson et al. (1997a) rejected the results of an additional survey conducted in 1985, which produced a lower value than either of the other two surveys, because it was not possible to correct the estimates for pups that had already left the ice and for those born after the survey. For hooded seals, unlike harp seals, this correction can be large and failure to account for it will result in a substantial negative bias.

2.2.3 Grey seal

The main breeding concentrations of grey seals are in the southern Gulf of St. Lawrence and on Sable Island, east of off mainland Nova Scotia (Lesage and Hammill 1999). Between 1976 and 1990 every pup born on Sable Island was counted and tagged, and this provides the best available time series of abundance for any of the Atlantic seal species. As numbers on Sable increased, these comprehensive counts became increasingly difficult and photographic aerial surveys were carried out in 1989 and 1990 (Bowen et al. 1999). Further aerial surveys using the same protocol were carried out in 1993 and 1997 (Bowen et al. 1999). Survey results were corrected for missed pups and pups born before and after the survey using techniques similar to those developed for harp and hooded seals. Pup production has increased by an average of 12.7% per annum since 1976.

In the Gulf, pup production in 1984, 1985, 1986, 1989 and 1990 was estimated by tagging pups and recording recoveries in scientific collections made at Anticosti Island in the Gulf, or in sighting surveys made on Sable Island (Hammill et al. 1998). An independent estimate of pup production in 1989 and 1990 taking account of migration between recovery sites was made by Myers et al. (1997a). Aerial surveys of pup production in the Gulf were made in 1996 and 1997 (Hammill et al. 1999a). If all available estimates of pup production are used, the annual rate of increase from 1984 to 1997 was 3.4% (Hammill et al. 1999a). However, Hammill et al. (1999a) suggest that the results of the 1997 survey may have been affected by poor ice conditions that could have caused high pup mortality before the survey. If the results of the 1997 survey are excluded, the annual rate of increase in pup production is 6.5%.

2.3 Mortality

The mortality suffered by Atlantic seals can be conveniently divided into that resulting from natural causes and that resulting from human actions. Human-induced mortality includes seals deliberately killed as part of the Canadian and Greenlandic seal hunts (including an allowance for seals that are killed but not recovered by hunters), and seals that die following entanglement in fishing gear. Clearly this mortality may vary substantially from year to year and needs to be explicitly documented. It is generally assumed that mortality from natural causes (such as disease, accident, starvation and predation) fluctuates around some long-term average and can be described by a single parameter. In populations that are not subject to large-scale human-induced mortality, natural mortality rates can be estimated from an examination of the number of animals in successive age categories. However, all of the Atlantic seal species have a history of exploitation or culling that is reflected in their age structure, making it virtually impossible to estimate natural mortality in this way. Instead, natural mortality has been estimated by fitting a population model to a time series of pup production estimates, and this process is described in section 2.5. In this section, we concentrate on the information that is currently available on human-induced mortality.

2.3.1 Harp seal

The number of seals killed and landed by Canadian hunters each year since 1972 has been documented in some detail by DFO. Information on the number of seals killed in Greenland has become available in a more erratic way, because of the dispersed nature of the communities in

Greenland. Precise information on the numbers of harp seals killed in Nunavut has been even more difficult to obtain. The reports of the ICES/NAFO joint working group on harp and hooded seals (e.g., Anon 2000) provide a convenient summary of all the available hunting statistics from Canada and Greenland. Recently, there has been considerable concern (e.g., Anon. 1997a) that these published statistics underestimated the actual number of seals killed each year, because they did not include seals that were shot but not recovered by hunters (seals "struck and lost" in whaling parlance), because seals were known to die as a result of entanglement in certain types of fishing gear, and because data on the scale of the Greenland hunt were not up to date. Although it has been argued that this additional mortality will be included in the estimate of natural mortality (see **2.5**) this is only strictly true if the level of mortality from these sources is roughly constant over time. If this mortality has been increasing, as seems to be the case for the Greenland harvest, or if it varies between age classes, then total mortality in recent years will be underestimated and in early years it will be overestimated.

In response to these concerns, Lavigne (1999) estimated the scale of the struck-and-lost mortality in the Canadian and Greenland hunts using published information. His estimates were reviewed by the National Marine Mammal Review Committee at its 1999 meeting (which was attended by Lavigne), and revised estimates of the struck-and-lost rate were agreed (Gagné 1999a). Information on the bycatch of harp seals in the gillnet fishery for lumpfish is now available (Walsh et al. 2000), as is reasonably up-to-date information on the size and age-structure of the Greenland catch (see Stenson et al. 2000a). Harp seals are known to have been bycaught in both the cod gillnet and trawl fisheries (e.g., Lawson and Stenson 1997), but the magnitude of this bycatch has presumably decreased, given the reduction in these fisheries.

Estimates of number of seals killed each year in the Canadian and Greenlandic hunts (including struck-and-lost mortality) and of bycatch in the lumpfish fishery are now incorporated in models of the dynamics of the Northwest Atlantic harp seal population (Healey and Stenson 2000), see **2.5**. However, some concerns must still remain about the actual struck-and-lost rate for adult and subadult seals shot in the water by inexperienced hunters (see Gagné 1999a), about the reasons for the dramatic increase in Greenland catches since the mid-1980s (from less than 20,000 to nearly 70,000 in some years), about the extent of "high-grading" (discarding of females) in years when seal penises fetched high prices, and about the scale of the small hunt in arctic Canada.

2.3.2 Hooded seal

Commercial hunting of hooded seals has been carried out since the nineteenth century. Between 1974 and 1982 the average annual harvest was 12,500 animals (Stenson et al. 1997a). This included a high proportion of adult females that were killed in order to gain access to their blueback pups whose pelts are particularly valuable. Following the closure of European markets for skins from "baby seals," killing of bluebacks (defined as animals that had yet to complete their first post-natal moult) was not permitted and annual catches in Canada have been highly variable. They have ranged from less than 100 in 1986, 1993 and 2000, to more than 5,000 in 1991, 1997 and 1998, and more than 25,000 in 1996 (ICES 2000). The very large catch in 1996 (which was 2.5 times the TAC) occurred because unusual ice conditions brought the breeding aggregations close to shore, allowing large numbers of young seals to be killed in a very short period. There has been an annual catch of around 7,500 in west and southeast Greenland since 1992 (ICES 2000) which mainly involves hooded seals from the Northwest Atlantic.

2.3.3 Grey seal

Although grey seal numbers were believed to have been reduced to relatively low numbers by extensive hunting in the nineteenth century, little was known about their abundance until the 1970s. An annual cull of between 114 and 2,375 animals was conducted by the Department of Fisheries and Oceans at colonies in the Gulf of St Lawrence and along the eastern shore of Nova Scotia between 1967 and 1984 (Zwanenburg and Bowen 1990). In addition, bounties were paid to licensed fishermen for a total of 4,379 grey seals between 1978 and 1990.

2.4 Pregnancy rate

If pregnancy and survival rates remain constant over time, then pup production provides a reliable index of the total size of a seal population. However, if these rates vary over time, then trends in pup production can be misleading. In order to understand the dynamics of a seal population it is therefore necessary to monitor pregnancy rates. Since pregnant animals may lose their foetus at any time during pregnancy, pregnancy rates recorded during the later stages of gestation provide the most reliable link between pup production and the size of the adult female population.

2.4.1 Harp seal

Data on late-term, age-specific pregnancy rates are available from females collected in Newfoundland and Labrador, primarily between November and February, since 1954. These data are summarized in Sjare and Stenson (2000). There are gaps in the time series from 1955-64, 1971-77, and in 1983 and 1984.

Bowen et al. (1981) analysed the pregnancy rate data collected up to 1979 and found that the percentage of animals pregnant increased from 85% to 94% over this period. Virtually all of this change was due to an increase in the pregnancy rate for animals less than 7 years old. As a result, the mean age at maturity declined from around 6 years in 1952 to 4.5 years in 1979.

Annual sample sizes since 1979 have been rather small and in some years (e.g., 1980, 1986 and 1988) there are no samples from certain age classes, and only one or two individuals from others. Clearly estimates of age-specific pregnancy rates for these years will not be reliable and some method for pooling the data across years must be found. Warren et al. (1997) used a series of 2x2 contingency tables to decide when to pool data from consecutive years. The resulting "harmonized" series of pregnancy rates is presented in Healey and Stenson (2000). In this series, the pregnancy rate for 5- and 6-year-old animals is elevated in the 1970s, and that of 7-year-old animals is slightly elevated from the mid-1960s to the mid-1980s. The pregnancy rate of animals 8 years and older declines steadily from 1980 onwards.

One disadvantage of the method of Warren et al. (1997) is that it results in sudden changes in the estimated pregnancy rate that have unfortunate consequences for predicted changes in pup production (see section **2.5.1**). Healey et al. (2000) fitted a continuous, non-linear function to the data for each age-class using non-parametric regression with kernel smoothing. The results of their analysis suggest that pregnancy rates for animals 7 years and older have declined steadily since the late 1960s, whereas pregnancy rates for 5- and 6-year-olds were at their highest in the late 1970s.

There has been considerable interest in the literature over the apparent relationship between late-term pregnancy rates and population size. A number of authors (e.g., Lett et al. 1981, Winters and Miller 1998) have derived a relationship between these two variables that they have then used to estimate how sustainable yield might vary with population size, and to estimate the equilibrium size of the Northwest Atlantic harp seal population in the absence of hunting. However, as the Joint ICES/NAFO Working Group on Harp and Hooded Seals has noted (ICES 2000), estimates of pregnancy rate are used in the calculation of population size and therefore the two time series are not independent. This makes it impossible to interpret the statistical significance of the predicted relationships.

Lett et al. (1981) used data from 1951 to 1977 to derive linear relationships between late-term pregnancy rates, mean age at first reproduction and total population size. They predicted that the Maximum Sustainable Yield (MSY) from this population was around 200,000 animals at a population size of 1.5-2.0 million. Equilibrium population size was predicted to be about 5.5 million, at which point the pregnancy rate would have declined to 0.62.

Winters and Miller (1998) used two different time series of population estimates and pooled pregnancy rate data from 1952 to 1992 to derive a linear relationship similar to that used by Lett et al. (1981). In this case the estimated MSY is 280,000 animals at a population size of 3.5-4 million, and the equilibrium population size is around 7 million.

Warren (1999) has cogently summarized the problems with this kind of analysis, where relationships are extrapolated well beyond the range of the available data. In addition, a linear relationship with population size is biologically unrealistic, since it implies that the pregnancy rate can be less than 0.0 when the population is above some threshold size, and greater than 1.0 when the population is below another threshold. Since pregnancy is a binomial variable, a logistic regression is more appropriate (see, for example, Boyd 2000).

The most recent estimates of population size for the Northwest Atlantic harp seal population use a smoothed series of pregnancy-rate estimates that are, to some extent, decoupled from the raw, year-by-year pregnancy rate data. **Figure 2.1** is a plot of these raw pregnancy rates against estimated population size for animals aged 5 and 8+. Although there is a negative relationship in both cases, the scatter of points is very much greater than implied by Figure 8 of Winters and Miller (1998) or Figure 22 of Winters and Miller (2001). Because total population size has increased steadily over the time period covered by these samples it is impossible, from this plot, to distinguish the effects of population size from the effects of other environmental variables that have been changing over time. However, a more detailed analysis, along the lines of Boyd's (2000) recent analysis of pregnancy data for UK grey seals, which includes year, female size, female age, date of collection, and some measure of food availability (such as capelin biomass) as explanatory variables should clarify this.

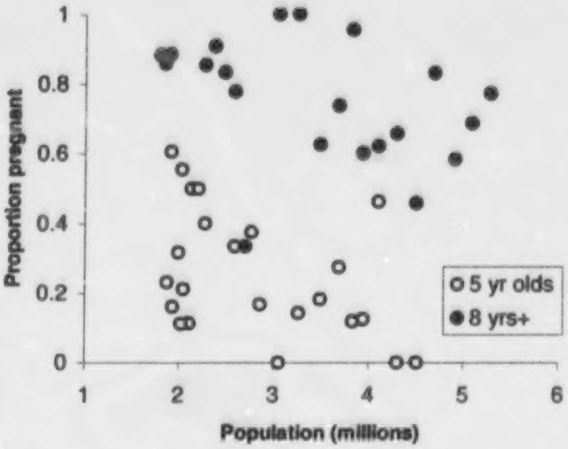

Figure 2.1. Variation in pregnancy rate with population size for harp seals aged 5 years and 8 years or more sampled between 1965 and 1997. Data provided by G. Stenson (DFO).

The current estimate of Replacement Yield (531,000) for the Northwest Atlantic population (Healey and Stenson 2000) is much larger than the Maximum Sustainable Yields calculated by Lett et al. (1981) or by Winters and Miller (1998). This is because the net productivity of the population has increased steadily with population size over the range observed in the last 30 years (1.8-5.3 million), rather than peaking at some intermediate population size as predicted by the Maximum Sustainable Yield calculations. Although the net recruitment rate of the population has declined since the 1970s, because of the decline in pregnancy rate, this has been more than compensated by the increase in population size. As a result, net productivity (net recruitment multiplied by population size – equivalent to the sustainable yield for a random harvest from the population) has increased steadily. **Figure 2.2** shows how net recruitment rate and net productivity for Northwest Atlantic harp seals have varied with population size between 1960 and 1999. Net recruitment rate is equivalent to the intrinsic rate of increase (r) of the population in the absence of any exploitation. This was calculated at each population size, using Goodman's (1980) simplified formula with the smoothed pregnancy rate time series of Healey et al. (2000), and adult and first year mortality values of 0.058 and 0.175 from Healey and Stenson (2000). There is no evidence of curvilinearity in the net productivity time series, suggesting that Replacement Yield will continue to rise if the population increases in size above its current level.

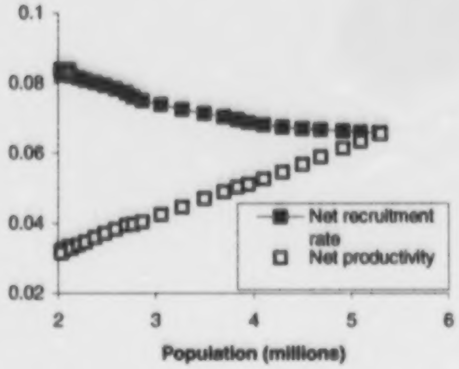

Figure 2.2 Variation in net recruitment rate and net productivity (calculated as net recruitment x population size/population size in 1999) for Northwest Atlantic harp seals between 1960 and 1999.

2.4.2 Hooded seal

No detailed data on late-term pregnancy rates for hooded seals in the Northwest Atlantic have been published in the last 20 years. Myers and Stenson (1996) provide values for the proportion of animals mature at each age from 4 to 9 (based on samples collected in 1979 and 1984). They then used data from Born (1982) on the overall pregnancy rate of animals shot in south Greenland to calculate age-specific pregnancy rates. Hammill and Stenson (2000) used a rather different set of age-specific rates that are derived entirely from samples collected in Newfoundland in the 1980s and 1990s.

2.4.3 Grey seal

Mansfield and Beck (1977) provided estimates of age-specific pregnancy rates for Northwest Atlantic grey seals. Zwanenburg and Bowen (1990) and Mohn and Bowen (1996) used these values to calculate variations in the size of this population, although they had to increase the pregnancy rate for animals 6 years and older to match the observed increase in pup production at Sable Island. Hammill and Stenson (2000) used age-specific pregnancy rates from seals collected in the Gulf of St. Lawrence (Hammill and Gosselin 1995) to perform similar calculations.

2.5 Total population size

2.5.1 Harp seal

Given a time series of age-specific pregnancy rates and removals, it is possible to construct a mathematical model of the dynamics of a seal population in terms of a small number of biological parameters (so long as these are assumed to be constant over time and age). These parameters can then be estimated by comparing a set of predictions from this model with observed values. The basic population model used to estimate harp seal numbers over the last 15 years was first formulated by Roff and Bowen (1983). They assumed either that the annual rate of natural mortality was identical for all age classes, over all years, or that the mortality rate for animals in their first year of life was three times the adult rate. They then estimated the adult mortality rate, and pup production in an initial year (1967) by comparing the model output to the statistical distribution of mark-recapture estimates of pup production for 1978, 1979 and 1980, and estimates of the relative sizes of the 1967 and 1968 cohorts and the 1971 and 1972 cohorts derived from the age structure of the catch of moulted male seals (see **3.1.2.1**).

In Roff and Bowen's method, the 1967 pup production value is needed to calculate the age distribution of the population in the initial year. To avoid this dependence on a single value, Cadigan and Shelton (1993) assumed that catches of whitecoat pups during the 1940s and 1950s were a constant fraction (s) of the total pup production, thus 1/s multiplied by the catch in each year is an estimate of pup production. They showed that pup production in any year could be rewritten as a function of s, the natural mortality rate (**m**) and the known history of catches and pregnancy rates. A series of estimates of pup production, with their sampling distributions, can then be used to obtain maximum likelihood estimates of s and **m** using weighted, non-linear, least squares techniques. These estimates can then be used to calculate total population size and replacement yield in any year. Initially, it was thought that the asymptotic variances of s and **m** could be used to calculate confidence limits for population size and replacement yield. However, Warren et al. (1997) showed that this underestimated the true confidence limits substantially, and confidence limits are now determined by running the estimation procedure many times using values for pup production resampled at random from the underlying distributions of these estimates.

The most recent published application of this approach is described in Healey and Stenson (2000). They estimated s and **m** using a harmonized time series of pregnancy rates derived from the approach of Warren et al. (1997), a set of age-specific removals that take account of struck-and-lost rates and by-catch, and pup production estimates for 1978, 1979, 1980, 1983, 1990, 1994 and 1999. These values were then used to calculate a time series of pup production and total population size values, and replacement yields for 2000 under a variety of age structures. These replacement yields can be divided into components for the Canadian and Greenlandic catches.

Healey and Stenson's (2000) general conclusions that numbers of harp seals have increased steadily since the imposition of catch limits in the 1970s and that this increase accelerated in the 1980s and early 1990s because of the low catch rates in these years seem to be robust. So does their conclusion that population numbers have been relatively constant since the mid-1990s. The increasing number of reports of vagrant harp seals south of the species' former range (McAlpine and Walker 1999, Stevick and Fernald 1998) appear to support the conclusion that the population has become much larger. However, McAlpine et al. (1999a) suggest that this increase in reporting is more likely to be the result of changes in prey availability in the seal's normal past range than in absolute abundance.

The predicted pup production estimates are, as noted by Winters and Miller (2001), a rather poor fit to the aerial survey values, a situation exacerbated by the apparent sudden transitions in the pregnancy rate time series that occurred in 1991 and 1995. However, the Panel was shown the results of a reanalysis of the data using the smoothed time series of pregnancy rates derived by Healey et al. (2000). This provides a more convincing fit to the aerial survey data. Stenson also repeated this estimation using the revised estimate of variance for the 1999 aerial survey (see section **2.2.1**), and assuming that the variance on the 1994 estimate could also be reduced by a similar amount if these data were reanalysed using the approach of Stahl et al. (2001). The model fit to these data is marginally better than that obtained with the current coefficients of variation. This revised estimate of population size in 2000 is about 10% higher than the estimate in Healey and Stenson (2000), whereas the estimate for 1970 is about 7% lower.

The confidence limits for population size and replacement yield estimates derived by Healey and Stenson (2000) are exactly that: if we repeated the seven estimates of pup production many times, then in 95% of the cases we would expect the estimates of population size and replacement yield to fall within these limits. However, sampling variability in the estimates of pup production is only one of the sources of uncertainty in the calculation of population size and replacement yield. Other obvious sources are error in the estimation of age-specific removals and in the time series of pregnancy rates. Warren et al. (1997) concluded that estimates of abundance were relatively insensitive to uncertainty in the year- and age-specific estimates of pregnancy rate. However, they considered only the effects of sampling variance in the pooled estimates of pregnancy following the use of the contingency table approach. The fact that a rather different time series was obtained using the kernel smoothing approach suggests that the pooling procedure itself involves additional uncertainty that needs to be accounted for.

2.5.2 Hooded seal

The only recent estimate of total population size for hooded seals was provided by Hammill and Stenson (2000). They used the difference between the results of the 1984 and 1990 estimates of pup production off Newfoundland to calculate an annual rate of increase for the population. They then calculated the first-year mortality rate that would be required to achieve this rate of increase with the observed values for age-specific pregnancy rate (see section **2.4.2**) and an annual mortality rate of 0.09, the mid-point of a range for this parameter assumed by Myers and Stenson (1996). They then assumed that these parameter values remained constant over time and used them to predict total population size in 1996. However, the 1984 and 1990 pup production estimates are not statistically different, and an alternative assumption is that the population was stationary over this period. This would give a higher estimate of first year mortality and lower predicted population size in 1996, especially if allowance is made for the possibility that the mortality rate for adult males is substantially higher than that for females, as it is in other sexually dimorphic pinnipeds.

The only evidence for an increase in hooded seal numbers since 1990 is the increased frequency of sightings of hooded seals south of their normal range in the last decade (McAlpine et al. 1999b). But, as for harp seals, McAlpine et al. (1999a) concluded that this was more likely to be the result of changes in food availability than overall abundance.

2.5.3 Grey seal

Mohn and Bowen (1996) calculated changes in the size of the Northwest Atlantic grey seal population over the period 1967 to 1995 using estimates of age-specific pregnancy rates from

Zwanenburg and Bowen (1990), an assumed pattern of age-specific survival rates (including lower rates for males than females), and pup production estimates from Sable Island between 1976 and 1990, and from the Gulf of St. Lawrence between 1984 and 1990.

Hammill and Stenson (2000) calculated the size of the same population in 1990 and 1996 using a slightly different set of age-specific pregnancy rates, the same set of pup production estimates for Sable Island, and a revised set of pup production estimates for the Gulf that included the results of an aerial survey in 1997 (but not the 1998 value). They assumed identical mortality rates for adult males and females.

2.6 Current management approaches and their impacts

2.6.1 Harp seal

The aim of the current management approach for Northwest Atlantic harp seals is to achieve a sustainable harvest that allows the seal population to maintain its numbers. This is achieved by setting a Total Allowable Catch (TAC) that is less than the calculated Replacement Yield. Healey and Stenson (2000) calculated that the Replacement Yield from 2000 onwards was 531,000. This is based on the assumption that natural mortality of 0 age seals is three times that of seals 1 year and older, and that 70% of the catch is made up of young of the year. Taking account of uncertainty in the pup production and reproductive data, the 95% confidence interval on this estimate is 373,000 to 693,000.

In order to estimate the portion of this Replacement Yield that can be landed by the Canadian commercial harvest, Healey and Stenson (2000) estimated levels of catches in Greenland and in the Canadian Arctic, as well as the struck-and-lost rates associated with these harvests, and mortality in bycatch. They adjusted the calculated Replacement Yield by these amounts and presented the Replacement Yield in units of potential Canadian Front and Gulf landings. The proportion of young of the year in the Canadian commercial harvest has varied from 70% to more than 90%. In 1999 the Canadian Front and Gulf actually took over 95% young of the year. Using the assumption that 90% of the Front and Gulf hunt would be age 0 animals, and accounting for struck-and-lost animals in this hunt, the Front and Gulf component of the Replacement Yield was estimated to be 257,000 animals with a 95% confidence interval of 102,000 to 342,000.

The catch data that are input to the model used to estimate Replacement Yield are not solely comprised of reported landings. The catch also includes bycatches in the Newfoundland lump fishery (Walsh et al. 2000) and the eastern United States (Waring et al. 1999), and estimates of animals struck and lost in the various hunts (Anon 1999). It is assumed that the struck-and-lost rate for young of the year is 5%, and that animals one year of age and older are subject to a 50% struck-and-lost rate. The entire arctic Canadian and Greenland harvest is assumed to have a struck-and-lost rate of 50%. That is, for every harp seal more than one year old that is landed, it is assumed that another is killed and not retrieved.

The bycatch in the lumpfish fishery was estimated at 17,000 animals (Walsh et al. 2000). The

Canadian Arctic catch was assumed to be 4,881 animals with another 4,881 struck and lost (Lavigne 1999, Anon. 1999). Bycatch in United States waters was estimated to be 398 (Waring et al. 2000). The Greenland catch in 2000 was estimated at 103,707 animals (Stenson et al. 2000b) with a similar number struck and lost. This estimate is based upon a trend derived from reported landings in Greenland in the late 1990s. The number is actually higher than any level realized to date and may be an overestimate. The 2001 Seal Management Plan (DFO 2001a) suggests that the Greenland hunt may have stabilized at around 80,000 animals. What is clear is that the Greenland harvest of harp seals has a substantial effect on the level of harvest that can be available to Canadian sealers.

There appears to be no formal co-management arrangement with Greenland to facilitate joint planning and management of the harp seal resource. The Panel wrote to the Assistant Deputy Minister of Fisheries Management within DFO for clarification. In his letter of reply dated 11 June 2001 the ADM advised "there is no arrangement that specifically supports the joint management or research of harp and hooded seal stocks between Canada and Greenland." This is surprising in light of the fact that "the harp seal stocks harvested in the Northwest Atlantic are found solely within the 200-mile limit of Canada and Greenland."

There is no formal mechanism to coordinate research on seals in Canada and Greenland. However, the joint ICES/NAFO Working Group on Harp and Hooded seals does provide a forum for research discussions and provides advice to support the joint management of seals. In addition, Canadian and Greenland scientists regularly discuss their respective seal research programs and these discussions currently involve the conduct of a joint satellite-tagging program intended to help document seal movements and stock boundaries.

Canada participates as an observer to the North Atlantic Marine Mammal Commission (NAMMCO). NAMMCO was established to contribute to the conservation, rational management and study of marine mammals in the North Atlantic.

In his letter the ADM states "unlike the structure in place for narwhal and beluga consultations, there is no formal agreement for the management and conservation of harp and hooded seals between Canada and Greenland." The dialogue that has taken place has been strengthened through the recent development of a detailed management compendium for seals. "Once completed and updated it will provide both parties with a clear understanding of the other's management practices." With respect to the means by which Canada takes cognisance of the Greenland hunt, the letter concludes: "While Canada does not identify a specific 'allowance' for Greenland when setting Canadian quotas, Greenland's activities are taken into consideration when establishing quotas for Canada based on the replacement yield estimate."

The Panel is of the view that Canada should seek a formal agreement with Greenland on the joint management of the harp seal herd, which spends its life exclusively within the economic zones of these two jurisdictions. The timing for such an agreement may be opportune if Canada is contemplating significant changes in its management strategy for the seal stocks that are important resources of both Canada and Greenland. If new management objectives are to be pursued the prospects of success will be enhanced if there is an effective bilateral arrangement whereby policy objectives are harmonized.

It is worthy of note that both Canada and Greenland are supporting their respective hunts through various means. In the case of Greenland these measures include a significant subsidy paid by Government to seal harvesters. While a joint management arrangement should focus initially on issues of biology and harvesting it may be appropriate for the arrangement also to address economic issues, including the harmonization of policies so as to place sealers in both jurisdictions on a level playing field.

It is probable that current Canadian TACs are achieving the aim of allowing the seal population to maintain its numbers. It is less clear that this approach conforms to the Canadian government's policy of taking a precautionary approach to the management of wild living marine resources, because there is no clear management objective associated with this aim. However, we note here that, if the objective of management is to maintain the harp seal population at its current level, then a precautionary approach would involve defining an acceptable probability of decline and calculating the TAC that was most likely to achieve this. If the Replacement Yield is used to set the TAC, then that probability is 50%. Alternative management aims are discussed in section 5.

2.6.2 Hooded seal

The current TAC of 10,000 for hooded seals in the Northwest Atlantic is based on the analysis of Myers and Stenson (1996), who calculated Replacement Yields as a proportion of pup production for a range of adult and juvenile mortality rates, and for hunts with different age structures. The 2001 Seal Management Plan states that the Replacement Yield is "between 24,000 and 34,000 animals, depending on the age composition of the hunt." However, this range of Replacement Yield values is for a specific combination of natural mortality rates (0.09 for adults, 0.27 for pups). If the full range of mortality rates considered by Myers and Stenson (1996) is used (and it should be remembered that there are no estimates at all of mortality rates in this population) Replacement Yield lies somewhere between 12,000 and 57,000. This is based on the assumption that pup mortality is three times adult mortality (as for harp seals). Clearly there is an urgent need for a reliable estimate of adult mortality to narrow the wide range.

Reported catches in Canada and Greenland have averaged 15,000 between 1993 and 1999 (ICES 2000). If the same struck-and-lost rate used for harp seals is applied to the Greenland hunt, total annual removals may have been around 23,000 animals. Although this is at the lower end of the range of Replacement Yields described above, it does not assure that removals on this scale are sustainable. Thus, the assumption that hooded seal numbers have been increasing steadily since 1990 (Hammill and Stenson 1990) is not necessarily valid, and a new aerial survey is urgently needed.

2.6.3 Grey seal

At present only small numbers of grey seals are harvested in Atlantic Canada, mostly in the Magdalen Islands and Cape Breton. Annual catches averaged less than 200 animals between 1994 and 2000. In 1998, the North of Smokey Sealers Co-op Limited (Cape Breton) proposed an annual hunt of 25,000 grey seals over a three-year period. This proposal was considered by the

Marine Mammal Review Committee at its 1998 meeting (Gagné 1999b), which concluded only that the proposed numbers seemed 'unrealistic' and recommended that the hunt should be restricted to adult males and juveniles. Hammill (1999) calculated Replacement Yields in 1999 and 2000 for the Gulf and Sable Island populations separately. The sizes of these yields depend on the age structure of the hunt, and on what rate of increase is assumed for the Gulf population. The calculated Replacement Yield for a hunt of pups only on Sable in 2000 was 27,300. The equivalent value for a summer hunt (made up of 20% pups and 80% animals one year and older) was 20,600. For the Gulf, calculated Replacement Yields in 2000 ranged from 2,200 (20% pups, 80% animals one year or older, 3.4% annual increase) to 8,600 (all pups, 6.5% annual increase).

The 1999 meeting of the Marine Mammal Review Committee (Gagné 1999a) noted that if the combined replacement yields were taken outside the pupping season (as seemed likely), this could easily lead to overexploitation of the population in the Gulf because animals from the two stocks haul out together at a number of accessible locations. The Committee therefore suggested that a removal of no more than 2,000 animals per year would have little long-term effect on either the entire population, or the Gulf component. Three hundred and forty two grey seals were taken in Cape Breton in 2000, 300 more than the annual average in the previous 5 years.

2.7 Other species

2.7.1 Harbour seal

Published accounts of the abundance of harbour seals in Atlantic Canada are hard to find. Boulva and McLaren (1979) estimated that the population was 12,700 in 1973 and thought that it was declining at 4% per annum because of a bounty program. Hammill and Stenson (2000) calculated that if the population had continued to decline at 4% per annum until 1976, when the bounty program ended, and thereafter increased at 5.6% per annum, the population size in 1996 would be 31,900. Some support for the assumption of an increase in numbers since the late 1970s comes from the results of aerial surveys in the Bay of Fundy conducted by Stobo and Fowler (1994). They found that there had been a significant increase in numbers between 1985 and 1992, but they could not estimate the magnitude of this increase or the size of the harbour seal population.

M. Hammill (DFO) provided the Panel with a verbal report on recent aerial surveys conducted within the Gulf of St Lawrence in August. The size of the population there was estimated to be 5,000 to 14,000, assuming that densities observed in areas that were surveyed applied across the species' range, and that 50% of the population was hauled out at the time of the survey. Including an estimate of 10,000 animals in the Bay of Fundy gave an estimate of 15,000 to 24,000 for the current size of the harbour seal population in Atlantic Canada.

There are no data on the current status of this population. However, there has been a spectacular decline in the number of pups born at Sable Island, from over 600 in 1989 to about 40 in 1997, which is believed to be the result of increased levels of shark predation in the waters around Sable Island (Lucas and Stobo 2000).

2.7.2 Ringed and bearded seals

Two other seals species, the ringed seal and bearded seal, also occur within Atlantic Canada. Small numbers of ringed seals breed along the Labrador coast, and bearded seal vocalizations have been recorded off northeast Newfoundland, suggesting that mating may occur in this region (B. Sjare, DFO, pers. comm.). Total numbers of both species in Atlantic Canada are very much smaller than for harp, hooded or grey seals and we have not therefore considered ringed and bearded seals in this report. However, we note that there may be competition for food between these species and harp seals in their summer range (see Wathne et al. 2000).

2.8 Conclusions and recommendations

2.8.1 Harp seal

Conclusions: The estimates of current population size appear to be robust. Suggestions that the population is declining rapidly under the current harvest are not justified.

Recommendations: Once clear objectives for the management of this population have been identified, a new approach to management that takes account of the uncertainty associated with the estimates of current population size and yield should be adopted.

2.8.2 Hooded seal

Conclusions: There are no reliable estimates of the current size or status of the Northwest Atlantic hooded seal population.

Recommendations: A new survey of the breeding aggregation off northeast Newfoundland is urgently required, as are better documented estimates of age-specific pregnancy rates, mortality rates, and the age-structure of the Canadian and Greenlandic harvest.

2.8.3 Grey seal

Conclusions: The exponential increase of the Sable Island colony is well documented (although there is an urgent need to publish the data for the last 10 years), but it is probably unlikely to continue for much longer. The situation in the Gulf of St Lawrence is less clear-cut. Recent survey results suggest that the number of animals pupping in this area is no longer increasing.

Recommendations: A reanalysis of the available data is desirable to see if the dynamics of Northwest Atlantic grey seals can be explained better by considering them as a single, geographically structured population with different first-year mortality rates in the Gulf and Sable Island colonies.

3. Economics of the seal hunt

3.1 Introduction

The Panel has examined the factors that shape the seal hunt and determine the level of the harvest. An understanding of the economics of the sealing industry is important in interpreting the historical pattern of landings and in predicting the future level of the harvest. Although the Minister of Fisheries and Oceans establishes the total allowable catches (TACs), the actual level of effort is determined by economic factors and by the management conditions under which the hunt is conducted. Effective quota management will ensure that economic factors do not cause the TAC to be exceeded. However, if the level of effort leads to a harvest that falls far short of the TAC because of poor market conditions or high costs, then the seal population may expand beyond the target level established (section 5.2). Managers need to understand the economic factors that may cause the harvest level to fall short of the quota or to exceed it.

Canada has the largest seal hunt in the world, directed mainly toward harp seals, most of it based in the Province of Newfoundland and Labrador. Seal hunting has been a highly variable activity over the years. Some of this variation has been shaped by government policy and management measures. Much of it has been the result of market forces and of changes in the demand for various seal products, such as oil, fat, leather and fur. In the quarter century after the end of the Second World War, landings of harp seals were well in excess of 200,000 animals (DFO 2001a, Fig. 2). From 1972 to 1982, landings were in the range of 125,000 to 175,000 animals annually. In the period 1983 to 1995, landings were typically in the 50,000 to 100,000 range and well below the TAC of 186,000. This reduced level of landings arose partly because of the ban upon harvesting of whitecoats, as well as from the removal of large vessels from the hunt.

In 1996, the hunt returned to a higher level, with harp seal landings of over 240,000. In 1998 the hunt was the largest in recent years, at 282,070 animals, exceeding the TAC of 275,000. The harvest remained high, at 244,522 animals in 1999, but declined to only 91,602 animals in 2000, as a result of weak markets, poor ice conditions and higher fuel prices. For the current year (2001) the harvest for harp seals was about 210,000 animals (industry sources, pers. comm.). Markets in 2001 were buoyant but ice conditions restricted access to the seal herds and prevented the TAC from being reached.

Harp seals have comprised more than 95% of the total seal landings in Atlantic Canada, with a much smaller take of hooded seals (about 4%). The harvest of grey seals has generally been quite low, and that of ringed and harbour seals even smaller. Most discussion of the sealing industry therefore revolves around harp seals. Seals are also harvested from the Magdalen Islands, the Quebec North Shore and Cape Breton Island, as well as in Nunavut, where ringed seals predominate. The Magdalen hunt has averaged about 11,000 the Quebec North Shore took an average of slightly fewer than 1800 animals (all harps) over the ten-year period from 1991 to 2000. Sealers in the area comprising Cape Breton Island and Prince Edward Island took about 1,000 seals per year (mostly harps, but with some grey seals). Sealers at the Newfoundland Front (East Coast and Labrador) took an average of 110,000 seals of all species, mostly harps but including 5,000 hooded seals and a few ringed, bearded and harbour seals. Those in the Newfoundland Gulf took an average of 22,000 seals, mostly harp seals with very small numbers of hooded, grey and bearded seals.

Most of the harvesting activity in Quebec takes place in the Magdalen Islands region. Burke Consulting Inc. (1999) reported that, until 2000, most of the seals harvested in Quebec had not been processed locally, but were sold to Carino Ltd., a subsidiary of G.C. Reiber and Company of Norway, which operates a seal-processing plant at Dildo in Newfoundland. This was confirmed by R. Simon (DFO, pers. comm.). A tannery began operation on the Magdalen Islands in 2000.

In the early 1970s, when landings were high, the estimated population of harp seals was reduced to just under two million animals. The present high population level of about 5.2 million harp seals is a result of the relatively low harvest that took place in 1983-1995, when the average annual harp seal harvest was 51,000, despite a TAC of 186,000 animals. After 1995, the market for seal pelts improved. The TAC was increased to 250,000 in 1996, and to 275,000 in 1997. It has remained at that level until the present and is established with the intent of ensuring that the harvest remains within the replacement yield, which was calculated at 531,000 for 2001 (Healey and Stenson 2000). Replacement yield is the number of animals that can be taken in a given year without reducing the total population in the next year. As noted in section **5.2.1**, the rationale for this management procedure is uncertain.

The TAC for hooded seals was increased from 8,000 to 10,000 in 1998. Catches have been very low since 1998. There is no TAC for seal species other than harp and hooded seals. There is a hunt for grey seals but the number taken has been small. A modest number of ringed seals is taken in the subsistence hunt in Labrador and in arctic Canada. Smaller numbers of bearded seals are also taken in that hunt. The Panel has not been tasked to consider the Nunavut hunt.

3.2 Value of the sealing industry

The Panel has attempted to obtain reliable information on the value of the sealing industry but has found that such data are somewhat imprecise and sometimes lacking in consistency. DFO (2001a) reports that the total landed value of the 1999 seal hunt was thought to be less than the 1998 value of $7.5 million. The Chief of DFO's Statistical Service has advised (Kieth Brickley, pers. comm.) that the total primary value of all seal landings in 1998 was $5.6 million, of which $5.4 million was reported in Newfoundland. This is a lower figure than is reported in the 2001 Management Plan (DFO 20001a), and substantially below the value reported by the Newfoundland Government. The Newfoundland and Labrador Department of Fisheries and Aquaculture estimated the 1998 value to harvesters at $8,750,000 (Department of Fisheries and Aquaculture briefing notes, hereafter DFA 2000). It is not clear why there are discrepancies in these measures of the value of the harvest to sealers. It had been suggested that DFO bases its estimate primarily on the amounts received by fish harvesters for pelts, without accounting for other products sold. DFO officials informed the Panel, however, that their data are derived from purchase slips prepared by buyers and that all products are included. Corresponding to this estimate of the value to harvesters the Province of Newfoundland and Labrador also estimates the export value to the Province for 1998 at $22,285,000 (DFA 2000). The Panel has not been able to obtain an estimate from DFO of the export value of the seal industry in any recent year. The Newfoundland estimates for 1999 (DFA 2000) show a total value to harvesters of $7,485,000 and an export value of $21,020,000, whereas DFO (2001a) reports landed value for 2000 of about $6 million.

The statistical data compiled by DFO during the course of the hunt are taken from two sources. For vessels in excess of 35 feet, there is a requirement to hail catches to DFO fishery officers (A.M. Russell, DFO Statistics, St. John's, pers. comm.). For smaller vessels, these fishery officers estimate the numbers taken and report them to head office. However, these data are subsequently verified and revised on the basis of purchase slips prepared by processors and other buyers. The Newfoundland Department of Fisheries and Aquaculture compiles their estimates of landed values by contact with processors, and their estimates of final product value come from the same source as the information compiled by DFO. Why these discrepancies exist with respect to landed values between the two departments remains a mystery, especially in light of the fact that both sets of data are compiled from industry sources. DFO does not report on product value and, upon request, has been able to provide the Panel only with very limited data on export value.

Newfoundland and Labrador (DFA 2000) reported a year 2000 seal hunt of 86,000 animals with an estimated total value to sealers of just over $2 million and an export value of just under $10 million. The average price for pelts received by harvesters fell from $26 in 1998, to $23 in 1999 and to $14 in 2000. This reduction in price impacted most severely upon the seal industry in 2000. In 2001, however, the average price paid to seal harvesters for pelts rose considerably to an estimated level of between $30 to $37 (industry sources, pers. comm.). In terms of product value, the production of seal oil for human consumption remained at a relatively high level, amounting in 2000 to about $5 million (DFA 2000). The product value for meat went from $660,000 in 1998, to $370,000 in 1999 and to $210,000 in 2000.

The production of seal oil capsules is a major development for the seal-processing industry over the past five years. Past practice was that seal blubber was exported as a raw oil product for further processing outside of Canada. Seal oil is high in omega-3 fatty acids, and is reported to have a number of therapeutic applications. There are currently four companies selling seal oil capsules in Newfoundland. These companies have made significant investments in processing facilities. Some of these investments have been supported by contributions from ACOA and from Human Resources Development Canada.

Up until recently the tanning of seal leather was undertaken outside the Atlantic region. This was a source of concern to governments who supported the further processing of sealskins in the region. The Province of Newfoundland and Labrador now has two tanneries, one in Catalina and the other in Baie Verte. Carino Ltd. has been involved for many years in the purchase of seal pelts. They continue to purchase wet skins for their tannery operations in Norway. Traditionally, the production of semi-processed and fully processed pelts has been the largest component of product value. However, in 2000 the value of pelts produced in Newfoundland and Labrador ($3,870,000, DFA 2000) was exceeded by the value of seal oil ($5 million) for human consumption.

3.3 Financial support from governments

The Royal Commission on Seals and Sealing in Canada (Malouf 1986) recommended that assistance be provided to the industry after the collapse of seal markets in 1983. DFO and other federal and provincial government agencies have provided significant contributions to support sealing associations and to promote the industry. The 2001 Management Plan (DFO 2001a) notes that "since 1986, DFO has provided more than $3 million for these purposes through the Atlantic Fisheries Adjustment Program and Grants and Contributions." The DFO assistance program ended in 1999, with $250,000 in funding for the sealing industry in that year. The Management Plan states "no financial assistance program was offered in 2000 and none is planned for 2001."

As pointed out by Burke Consulting Ltd. (1999), the production of seal meat for human consumption remains very small, notwithstanding the efforts to encourage expansion. That study noted that the amount of seal-meat production in Newfoundland in recent years has been directly correlated with the level of subsidization provided by government. In Table 4 of his report Burke documents the level of subsidies from 1994-95 to 1999-2000. He notes that such subsidies were scheduled to expire in 1999.

The magnitude of contributions from various government departments is difficult to determine with any precision. The Canadian Institute for Business and the Environment (Gallon 2001) provided a detailed list of such contributions. In its press release of 11 June 2001, the Institute stated that the study found at least $20 million in provincial subsidies to the East Coast seal hunt since 1995. The author of the report was quoted to have said that "between 1995 and 2000, close to $3 million per year was granted in government subsidies to the sealing sector." The International Fund for Animal Welfare (IFAW) financially supported this study.

The report concluded that, without government subsidies, the sealing industry would not survive other than as a cottage industry on a seasonal basis. It also contended that the seal hunt was maintained artificially by the three-year program of federal and provincial government seal-meat subsidies. The report recommended that the provincial and federal governments eliminate subsidies to the sealing industry sector.

The issue of the level of contributions from government has been controversial. Southey (1997) attempted to measure the magnitude of the subsidy and to estimate its impact. His estimate of the output of the industry in 1996 was $8.96 million. He deducted purchased inputs of $2.65 million to arrive at a value added of $6.31 million. His estimate of government subsidies for meat transport and processing amounted to $1.72 million for 1996. He estimated that a further $1.67 million is spent by government on inspection, rescue, and for industry support. Deducting these two items produced net potential benefits of only $2.9 million. The Panel is not aware of any comparable studies of other harvests (of fish or marine mammals) that would provide insight on whether the value added in the sealing industry is disproportionately dependent upon the level of financial support from government. The Panel also lacks confidence that the economic data available with respect to the sealing industry are sufficiently reliable to undertake a credible critique of studies such as the Southey (1997) and Gallon (2001) reports.

Southey (1997) estimated that the value added by the seal hunt is 0.06% of the gross domestic product of Newfoundland and that the commercial hunt added only the equivalent of 100-120 full-time jobs. For each full-time position in the sealing industry, Southey concluded, Canadian taxpayers spent $28,250 to $33,900.

Southey (1997) stated that, in 1996, at least 30,290 seal penises were collected and processed with a value of close to a million dollars. He found that the sealing industry was heavily dependent upon meat subsidies and the sale of seal penises and that these constituted 55% of the revenue of sealers and boat owners, after paying for fuel, ammunition and other inputs. He concluded that the net value of the seal hunt to Canada as a whole is zero, taking into account the opportunity cost of labour and capital.

IFAW provided the Panel with a partial list of "Canadian Government Sealing Industry Costs and Subsidies from 1994 to 2000." This list adds to $20,669,942. The largest single components relate to DFO (including Coast Guard) costs on the ice for the seal hunt in Newfoundland ($5,957,000) and corresponding costs on the ice for the seal hunt in Quebec ($1,820,000). These documents were supplied to the IFAW by DFO as a result of requests under access to information.

The comments above make it clear that the Panel has found it difficult to assemble a comprehensive compilation of contributions to the sealing industry. It is also difficult to make judgements on whether these contributions are commensurate with corresponding support levels to other industries. Any assessment of the level of support would have to examine normalized expenditure patterns in order to determine whether the incentives have unduly distorted the operation of the free market. In reviewing DFO correspondence on the meat subsidy, the Panel noted that, apart from budgetary considerations, there was concern that the meat subsidy was encouraging the harvest of larger and older animals, which have a lower pelt value. The meat subsidy has now been phased out, as has core funding from DFO to various industry organizations.

While it is extremely difficult to document the magnitude of government contributions and to compare these with other industries it does appear that DFO has made a policy decision to discontinue providing financial support. Whether other federal departments or provincial governments have made a similar decision is not apparent.

Although Canada conducts the largest hunt for harp seals in the world, this species is also hunted by Greenland and Norway. Canada was once also one of the major producers of hooded-seal products. Hooded seals are also subject to a hunt in Greenland and in Norway. While the Panel does not have recent information on subsidies provided by these countries to their sealing industries, it is known from participation by a member of the Panel in an industry symposium in Nuuk, Greenland, on 20-21 March 2001, that both countries have provided substantial financial support. In assessing the level of contributions to the sealing industry by governments in Canada the corresponding levels of support given in other countries that compete in the same markets must be recognized. Canadian and Greenlandic sealers are harvesting from the same biological resource and Canadian sealers operate within a quota, while sealers in Greenland do not.

The expanded hunt in 2001, compared with 2000, was the result principally of market factors. The market for fur in general and for seal fur in particular has improved. While there has been no firming of the weak market for seal meat, the market for seal oils has continued to be strong. Industry representatives view the longer-term prospects for the industry in a positive light. In the view of the Panel, the long-term trend over the past 20 years does not provide the basis to project that a TAC in the order of 275,000 animals is likely to be taken every year.

3.4 Costs of science and management

The Panel has attempted to assemble information on expenditures on science and management relating to seals. Data were provided (R.P. Jones, DFO, pers. comm., 1 September 2000) for the fiscal years 1998/99, 1999/2000 and 2000/2001. These data show that expenditures on science declined from $1,048,776 to $930,149 to $557,247. However, the funding level in any given year is affected by special funds allocated to major activities. For example there was significant funding for the aerial survey in fiscal years 1999/01 and 2000/01. Such a survey is conducted only every five or six years and has to be recognized in assessing year-to-year changes in expenditures.

The Panel was also provided with data on seal research expenditures for 1995/96, 1996/97 and 1999/2000 (D. Rivard, DFO, pers. comm., 10 July 2001), and information on groundfish research spending for the same years. The data on seal research are significantly different from those supplied on 1 September 2000, noticeably so for the one year in common to both communications, namely 1999/2000. These data show a reduction in seal research expenditures for the Newfoundland, Laurentian and Maritime Regions combined, from a little less than $2 million in both 1995/96 and 1996/97, to $1.2 million in 1999/2000, notwithstanding the fact that the 1999/2000 data include significant expenditures relating to the 1999 aerial survey.

The Panel requested data on research expenditures on seals in each of the Newfounland, Laurentian and Maritimes Regions over the past 10 years, along with information for corresponding years on groundfish science expenditures. DFO Head Office was unable to provide data on a comparable basis for groundfish over the ten-year period, but did give expenditure data on both seals and groundfish science for the three years noted above. While the trend for seal research was downward, the data reported to the Panel showed science expenditures on groundfish in the $16 to $17 million range over those same three years.

In his response to the Panel's request for research expenditures on seals, the Regional Science Director for the Laurentian Region (J. Boulva, pers. comm., 6 June 2001) gave a description of the current year seal research program and a summary for the last 10 years in that Region. It is clear that there are many competing demands for funds at the regional level and that marine mammal research has to be accommodated from the A budget as well as from application-driven funds, which are either funded by DFO Head Office or from outside of DFO. Over the ten-year period from 1992/1993 to 2001/2002 the allocation between A budget and application-driven funds has been roughly 50/50, with $1.2 million in each category. Over the 10-year period, 90% of salary costs have been funded from the A budget while over 78% of operating and maintenance cost and 100% of capital costs have been financed by application-driven funds.

In the conduct of research it is vitally important to plan projects that go beyond one year. To this end, multi-year commitments must be made. This is difficult to achieve within the current environment where stability of funds cannot be relied upon, and where research priorities must adjust to fit the issues of the day. The result is that scientists must now devote more and more time to the search for external funding. The time frame for these special externally funded programs has also shortened. As Dr. J. Boulva (DFO, pers.comm, 6 June 2001) notes: "the life of a special program is [now] three years or less," where it used to be five, and "it is almost impossible for funding to be carried from one fiscal year to the next." The Panel also notes with concern the statement that "priorities are decided according to availability of funding," as such availability may bear no relationship to the research priorities that flow from longer-term management and science requirements.

In its examination of the annual spending of the Laurentian Region for each of the past ten fiscal years the Panel noted that both total spending and A budget funding reached a maximum in 1993-94. This can probably be explained by the cost of the 1994 aerial survey, although the Panel is not aware of the actual cost of this survey. The average total spending on marine mammals at the Maurice Lamontagne Institute, Québec, over the past ten years, including both A base and special funding from research grant applications, was $239,700. The Panel notes a significant decline in the total annual spending in the years from 1998/1999 to 2001/2002, with the exception of 1999/2000, which may have been a result of the aerial survey in 1999. In fiscal 2000/2001 total spending was $122,000, about half of the 10-year average, while in 2001-2002 the total was marginally higher, at $125,000. It should be noted that the information for the Laurentian Region provided to the Panel does not conform to that provided by DFO Head Office for the three overlapping years, where the information can be compared.

DFO Maritime Region (Wayne Stobo, pers. comm., 9 July 2001) provided seal research expenditures, organized into base funds and special "high priority" funding (e.g., the former Seal Worm Intervention Program with Dalhousie University). These data were given for 1995/96 to 2000/01 with the comment that base funds would have been "fairly stable" over the period 1990/91 to 1994/95. Base funding and infrastructure expenditures continued at a level of about $264,000 into 1995/96 and 1996/97. When supplementary "high priority" funding is included, the total funding allocations over the six fiscal years beginning in 1995/96 were $764,500, $645,000, $183,600, $193,100, $215,500 and $173,700. The drop in funding for the 1997/98 fiscal year was the result of Program Review. Funding for 2001/02 is not yet finalized but it is understood that it will be in the same order as that of 2000/01. These data do not fully match those provided to the Panel by DFO Head Office (D. Rivard, pers. comm., 10 July 2001), but the same general pattern is evident, whereby, subsequent to 1996/97, a substantial decline occurred in the amount of resources available for seal research. The Panel notes this decline with concern. The largest reduction is in the supplementary or "high priority" funds, which declined from $500,000 in 1995/96 to $19,500 in 1997/98. This funding moved up to $49,700 in 1999/00, but declined slightly the following year.

Unfortunately, the information requested from the Newfoundland Region of DFO was not received in time for the Panel to include any reference to it in this report.

When spending on science, fisheries management, helicopter costs, fixed-wing surveillance, and vessel costs are combined, the following are the resulting costs to DFO of managing the seal harvest in the Newfoundland Region from 1995/96 to 1999/2000 (Lily K. Abbass, DFO, pers. comm., 30 January 2001):

1999/2000	$1,094.2 million
1998/99	$1,593.1 million
1997/98	$1,783.9 million
1996/97	$1,702.5 million
1995/96	$2,338.1 million

The amount of vessel time logged by DFO/Coast Guard vessels had not been tracked until the merger of DFO and the Canadian Coast Guard, five years ago. Specific amounts of effort within a management program are not tracked, and DFO staff have estimated these amounts. Another caveat that came with the data is that the costs shown do not include administrative overhead, nor do they show the costs of capital, ships, vehicles, etc., used in the delivery of programs. The numbers are based heavily upon estimates.

3.5 Future prospects for the sealing industry

The Seal Industry Development Council and the Canadian Sealers Association takes the view that the sealing industry has large potential for growth (brief, **Appendix 3**) They believe that the industry should be based upon good conservation practices and they oppose any notion of a non-consumptive harvest. They advocate the removal of the prohibition upon the import of seal products into the United States under its Marine Mammal Protection Act. Federal and provincial governments have supported this initiative.

Another constraint noted by the industry is the fact that seal meat is considered under Canada's food regulations as a fish product. This means that sodium nitrate cannot be added to extend shelf life. The sealing industry has requested that seals not be treated as fish in this context, but rather as marine mammals.

The Seal Industry Development Council and the Canadian Sealers' Association have made a number of recommendations in their brief to the Panel (**Appendix 3**). In addition to recommending that trade barriers be addressed, they have recommended that governments work with the industry on public education and promotion projects. They recommend that further clinical trials be undertaken to demonstrate the efficacy of seal products from a nutritional and therapeutic standpoint, and that there be an overall five-year development plan for the sealing industry.

The Province of Newfoundland and Labrador also provided a brief (**Appendix 3**) to the Panel that estimates that in 1999 the industry employed approximately 250 plant workers and 2000 harvesters. The Department projects that in 2001, the provincial seal harvest will employ in excess of 400 plant workers and upwards of 4,000 sealers, "as well as spin-off employment in trucking and infrastructure," and anticipates that "the value of the seal industry will increase dramatically, as new markets develop for more valuable Omega-3 oil products, high-grade pelts, and meat products." This brief recommends that trade barriers such as those arising from the Marine Mammal Protection Act in the United States be addressed, and that the Government of Canada continue to support seal-development initiatives in partnership with industry participants, provincial/territorial governments, and academic institutions. This would include activities relating to harvesting, product and market development, and processing.

3.6 Damage to fishing gear

The Panel has not heard much evidence on damage to fishing gear, which appeared to have been a major concern for many who presented to the Royal Commission on Seals and Sealing (Malouf (1996). However, Cairns (2000) presented some recent survey results based upon responses from 281 fish harvesters in PEI, in which most (81.5%) respondents indicated that seal populations are increasing in their areas. More than half mentioned harbour seals as widely distributed and spreading, about 40% mentioned grey seals, and fewer reported harp and hooded seals. The reported cost of seal-gear interactions was $6.2 million, which is 6.1% of the total landed value of commercial fisheries. However, Cairns (2000) notes that "Most ($5.6 million of $6.2 million, 90%) economic losses estimated from respondent reports are due to catch losses," and that "such estimates are highly subjective." About half of the total estimated loss was in the lobster fishery. "The true cost of seal-gear interactions is likely much lower than the $6.2 million calculated from respondent reports." Moving gear out of areas of seal concentrations was reported to reduce gear conflicts to some degree, but respondents felt that such relocations "reduced their fishing income because the new locations had poorer fishing success." Nevertheless, it is clear that seal-gear interactions are widespread, and that losses are substantial for some fishers. Seals were reported to steal gilled fish, make holes in nets, and scare fish away from nets, and (Cairns 2000) concluded that "seal-gear interactions on Prince Edward Island cause harm to both seals and the fishery, and detrimental effects are likely to increase if seal populations continue to grow," and that "many respondents suggested, often forcefully, that the only solution to seal-gear conflicts is a large-scale cull."

3.7 Proposed changes in legislation

The Panel has reviewed a document commissioned by the IFAW and prepared for primary publication by M.L. Campbell and V.G. Thomas of the University of Guelph, dated 4 August 2000. Since implementation of the recommendations of this document could have many effects on the economics of the hunt and financing of research on seals, it is considered briefly in this section

The document speaks to the absence of comprehensive programs for the conservation of marine mammals and the lack of explicit laws to protect marine mammals in Canada. Marine mammals are defined currently under the federal Fisheries Act (R.S.C., 1985) as fish. The authors contend that programs designed to manage the exploitation of fish stocks do not address the specific conservation issues of marine mammals. They cite recommendation 41 of the Royal Commission on Seals and Sealing in Canada (Malouf 1986): that responsibility for the management of seals on the Atlantic and Pacific Coasts should be transferred to an organizational unit within the

Department of Fisheries and Oceans separate from the Fisheries component of the Department.

The Panel recognizes the need for an expanded commitment to scientific research for the purpose of improved management of seals. However, the issues raised in the paper by Campbell and Thomas are much broader in scope than the evaluation of science, and its recommendations go well beyond the Panel's Terms of Reference. If the Panel had set out to develop recommendations on the legislative, institutional and management issues addressed by the brief, it would have identified them clearly in its call for public input.

3.8 Conclusions and recommendations

The seal hunt appears to be recovering from the poor market conditions of the past few years, even though there is some reason to believe that the level of subsidy is declining. The recovery appears to be more related to improved market conditions for sealskins and seal oil than to operating subsidies. The Panel has not been mandated to undertake a detailed economic examination of the industry or to make recommendations for its future direction. However, the Terms of Reference require that the final report of the Panel advise if an optimum size of the seal population can be identified, and, if so, provide advice on management strategies to attain such an optimum population. The economic outlook, and the policy framework within which this outlook is realized, contribute significantly to the design of management strategies.

The Panel has had difficulty in accessing consistent and accurate data on the economic value of the sealing industry to sealers as well as the product value of seals. The Panel has also had difficulty in determining the level of financial support provided to the sealing industry by government. Government should be more transparent with respect to the level of support it provides to the sealing industry, whether directly in the form of subsidies to the industry, or indirectly through research into seals and their management, and the provision of icebreakers during the seal hunt.

4. Prey consumption by seals and impacts on fish stocks

4.1 Introduction

This subject was dealt with at length by the Royal Commission on Seals and Sealing in Canada (Malouf 1986, chapter 24 on "Impact on Fish Stocks and Catches"). The Commission sought answers to the following questions: What, and how much, do seals eat? How much of this consists of commercially important fish species? What is the effect of these removals by seals on the stocks of commercial fishes? How do these effects of seal predation on commercial stocks further influence these stocks?

The Royal Commission attempted to answer these by adding estimated mortality due to seals to that attributable to other natural sources and fishing. Some assumptions and shortcomings of this approach are lucidly reviewed by one of the Commissioners (Gulland 1987). Nevertheless, the Commission was bold enough to estimate the dollar values of fish removed by seals throughout the Canadian East Coast (Malouf 1986, Table 24.13).

The Panel's assessments of the current state of understanding of the prey consumption and possible impacts of seals on fish stocks in Atlantic Canada is organized as follows: First we consider techniques used for assessing consumption of prey by seals (**4.2, 4.3**), then the general expectations for recoveries of diminished fish stocks (**4.4**), possible effects of environmental change (**4.5**), and broad arguments that have been presented concerning seal predation (**4.6**). Almost all the information pertinent to possible impacts of seals on groundfishes, including cod (*Gadus morhua*), in Atlantic Canada is specific to the management Divisions and Subdivisions of the North Atlantic Fisheries Organization (NAFO). We organize our detailed analyses accordingly (**4.7-4.11**). Possible impacts of seals on wild Atlantic salmon (*Salmo salar*) and on finfish aquaculture (mostly salmon) are given separate treatment (**4.12** and **4.13**).

In reviewing and analysing information on possible impacts of seals, we have kept in mind the recommendations by an international panel of the information required for scientific evaluation of proposed marine mammal culls (**Table 4.1**). There is published information on (i) and (ii) of that table, much of it in up-to-date DFO Stock Status Reports and Research Documents available on the Web. Information on (iii) and (iv) of **Table 4.1** is more limited, but has been used in some recent attempts to understand seal predation in Atlantic Canada within multispecies assemblages, to which we give close, critical attention.

4.2 Techniques currently used for assessing seal consumption

Estimates of consumption of prey by seals in Atlantic Canada have used the kinds of information indicated under (i) of **Table 4.1**. Identities and sizes of prey are estimated from remains (usually hard parts, such as fish otoliths) found in gut contents or faeces collected at haul-out sites to estimate frequencies, weights and energy contents of the original prey items. Then total energy requirements of seals of different ages, based on laboratory or field studies, are combined with estimates of the numbers of seals of the given ages in the population to calculate the total

Table 4.1 Data for evaluation of proposals to cull marine mammals based on fishery impacts, from UNEP (1999, Table 2)

(i) Marine mammal:
  - distribution and migration
  - per capita food/energy consumption
  - diet composition, including methods of sampling and estimation
  - demographic parameters

(ii) Target fish species:
  - distribution and migration
  - demographic parameters (weight at age, age at spawning, etc., commercial catch per unit effort
  - details of assessment models and results

(iii) Other predators and prey of the target species:
  - abundance, amounts consumed, details of stock assessment if any

(iv) Other components of the ecosystem
  - 2-way matrix of "who eats whom" with estimated or guessed annual consumptions
  - estimated abundance by species

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quantity of each prey species consumed. Finally, estimates of geographical and seasonal distributions are used to apportion prey consumption among regions, usually NAFO Divisions or gross categories within Divisions (e.g., inshore and offshore). In recent years, more detailed information on the distributions and movements of seals has been obtained from "satellite tags" placed on the bodies of captured and released individuals.

The directions of the biases in estimates of diet composition from stomachs or faeces are well known, and some allowance can be made for these in interpreting the data (e.g., Bowen and Harrison 1994). In particular, these techniques have been criticized for underestimating the importance of commercially important species in seal diets. Both methods, using stomach contents or faeces, rely on the presence of relatively undigested hard parts from prey in the samples and cannot account for prey without identifiable hard parts, or when hard parts are not ingested or are digested very rapidly. For example, it is often claimed that seals may eat only the bellies of large fish and that these size classes are therefore under-represented in the estimated diet.

The most serious shortcomings in the quality of information available up to 1996 were the small sample sizes for some seasons and regions, as indicated in CCFI (1997) and summarized on **Table 4.2**. Diet quality is indeed probably the largest source of calculable uncertainty in the estimates of consumption by seals (Shelton et al. 1997). Resampling methods are just beginning to provide better confidence limits, but these do not incorporate all sources of variation of consumption of prey. No attempt appears to have been made to estimate uncertainties of energy requirements.

Table 4.2 The quality of data on summer and winter diets of harp seals in Atlantic Canada as compiled from sources up to 1995 in CCFI (1997, Table 5.3)

	Summer		Winter	
NAFO Division	Pup	Non-pup	Pup	Non-pup
2J	poor	poor	moderate	moderate
Nearshore 3K and 3L	good	good	good	good
Offshore 3K and 3L	moderate	moderate	moderate	moderate
3Ps	poor	poor	poor	poor
4R	good	good	good	good

Related to concerns about the quality of data, is the fact that estimates of prey consumption by seals have changed over the years. For example, Stenson et al. (1997b) provided a "preliminary estimate" that total consumption of Atlantic cod by harp seals in the NW Atlantic in 1994 was ~144 Kt, whereas Hammill and Stenson (2000, Table 8) gave consumption in 1996 as ~91 Kt. Although such changes have led some stakeholders to express concern about the validity of the science involved, these reflect the way in which science does and should proceed, by improving techniques and obtaining more and better information. We consider and explain such changes in the various areas of Atlantic Canada (**4.7-4.11**), and use current, largely published sources as the best available, with due acknowledgement that these supply **minimal** uncertainties of estimated consumption of any prey species by seals. There are additional problems for rarely eaten prey species, and it may be impossible to obtain reliable estimates for species like Atlantic salmon.

4.3 Other techniques for assessing seal diets

The following techniques have been also used for assessing seal diets:

1. Serological tests for the recent consumption of different prey species (Pierce et al. 1990). These do not produce quantitative data on amounts consumed and have not been applied to seals in Canada.

2. Stable-isotope ratios in tissue samples. These only give information on the balance of trophic levels (e.g., zooplankton, forage fishes, fish predators) from which past food has been secured by seals. Nevertheless, this can give some insights into changes in food types over time or raise questions about the apparent balance of food types based on traditional techniques (e.g., Lawson and Hobson 2000). We lack any such information for specific regions and stocks.

3. The most promising new technique aims to assess diets of individual seals by statistically fitting the kinds and amounts of different fatty acids in potential prey species to the fatty acid profiles obtained from seal blubber samples or milk (Smith et al. 1997, Iverson et al. 1997). It has the great advantage of potentially integrating past diets over time. Some potential shortcomings may result from the fact that "fatty acid variation is much greater in fish than in marine mammals. If for example cod had extreme changes in diet, this may make it seem like another species and perhaps not [possible] to detect" (response to questions in Fanning 2000). However, Kirsch et al. (1998) fed captive seals with cod that had been fed either lean squid (*Loligo* sp.) or fatty mackerel (*Scomber scomber*) and found that "both cod and [its] prey . . . consumed by a larger predator [e.g., seals] can . . . still be distinguished from one another." Information from this technique is not yet available for assessing diets of seals in Atlantic Canada, but some preliminary results are given in section **4.11**.

4.4 The slowness of recovery of groundfish stocks

Seal predation as a cause in the major **collapses** of Canadian Atlantic groundfish stocks was not generally promoted as an explanation in interviews with either scientists or stakeholders (individual fishers, union and industry representatives), although advanced as one cause for collapse of northern cod by Winters and Miller (2001). Widely differing views, however, are held on the possibility that seals may be **inhibiting recoveries** of some stocks that have been greatly depressed by overfishing or other causes.

Hutchings (2000) amassed empirical evidence that very slow or complete lack of recovery has characterized a wide range of marine fish stocks greatly depleted by overfishing. Hutchings argued that this is expected from both the intrinsically low potential rates of increase of many such stocks and, among other causes, from the impact of bycatches from closed stocks after they are greatly depleted. This does rule out any possible cause of inhibition, but does indicate that removal of one such cause may not itself lead to rapid response of a depleted fish population.

Of particular interest are Hutching's (1999) simulations showing that the potential population rates of increase of Newfoundland Grand Banks cod are very low, and particularly sensitive to changes in either pre-adult or adult mortality rates. For example, a population of cod maturing at age 4, with an instantaneous adult mortality rate of 0.2 (~19% per year) was calculated to increase at 15% per year. Increasing this mortality rate by 0.1 (to 26% per year) reduced the population rate of increase to 12% per year. To cause similar reductions in population rates of increase, individual growth rate (affecting age of maturity and fecundity) had to decline by about 50%. This suggests that reductions of food availability and perhaps other negative changes in environmental quality that affect growth rate, may be less important in recovery of cod populations than changes in predation rate that directly increase mortality.

4.5 Environmental change

Changes in the marine climate of Atlantic Canada during the 1990s have been paralleled by notable shifts in distribution of both seals and their predominant prey, capelin (*Mallotus villosus*) and arctic cod (*Boreogadus saida*). During the early 1990s capelin may or may not have declined in biomass, but certainly shifted their distribution so that most were on the southeastern parts of the northeastern Newfoundland Shelf during the autumn surveys (Lilly and Simpson 2000). The change in distribution during the early 1990s is also clear in plots of their occurrence in cod stomachs (Lilly 1994). During the same period, capelin spread to the eastern Scotian Shelf and further into the Gulf of St. Lawrence (Carscadden et al. 2000). Arctic cod also expanded their distribution southeastward, and their overall biomass off Newfoundland appeared to increase (Lilly et al. 1994, Lilly and Simpson 2000). Beginning at least by the mid-1990s, there were also apparently abrupt changes in the distribution of both harp and hooded seals, when the overall population of harp seal numbers was more or less constant (see **3.1.5.1**). Southeastward shifts in distribution of harp seals to the northern Grand Banks appear to have begun in the early 1990s (Lacoste and Stenson 2000). Many stakeholders in Newfoundland stated from direct experience that harp seals in the mid-1990s became more numerous in inshore waters and began to linger into spring and summer. Others stated that seals have appeared in some Newfoundland and Labrador estuaries and rivers that they had not hitherto frequented. Although most of these are presumably harbour and grey seals, a brief from the Salmonid Association of Eastern Newfoundland (see **Appendix 3**) reports that "reputable" observers have noted "a dramatic increase in the amount of time [harp and hooded seals] remain in and around the estuary of many rivers." Harp and hooded seals also began appearing in numbers in Nova Scotia and New England around the same time (**3.1.5.1**).

There is some evidence of a recent shift back to long-term average marine climate regimes in Nova Scotia and the Gulf of Maine (e.g., Drinkwater et al. 2000), and in Newfoundland and southern Labrador (Colbourne 2000). There is recently also an apparent northward retreat of arctic cod and northward advance of capelin in Newfoundland waters (Anderson et al. 1999). Stakeholders in Newfoundland, however, have not noted a similar return of harp seals to their earlier ranges and habits. Furthermore, on Sable Island, Nova Scotia, where exceptional numbers of harp and hooded seals have occurred in recent years, numbers were still high in winter-spring 2001 (D. Bowen and Z. Lucas, pers. comm.). In addition, short-term fluctuations, such as occurred in the pelagic zones of NAFO Divisions 2J3KLNO in 1999 (summarized in Dalley et al. 2000), complicate analysis and prediction. It is thus uncertain if harp seals in particular will soon return to their original patterns of movements and distributions.

Environmental change has also been implicated in cod body condition, mortality and recruitment success. Such matters are considered in context of the various NAFO Divisions (**4.7-4.11**).

4.6 General arguments concerning impacts of seal predation on fish stocks

The following very general arguments about the role of seals in the recovery of groundfish populations include those submitted to the Panel Chair by the Fisheries Resources Conservation Council (attachment to letter from F. Woodman, Chairman FRCC, 12 June 2000). These arguments can conveniently be used to capture the spirit of a wide range of submissions made to the Panel.

4.6.1 Seals consume fish that could be taken by fisheries

It has been argued that if analysis indicates that eliminating or reducing fishing mortality will aid in recovery of particular fish stocks, then reducing mortality due to seals consuming those same stocks must also benefit this recovery.

It was often assumed in earlier literature that the total numbers of young groundfish entering a fishery were largely unrelated to the abundance of their parents (a lack of stock-recruitment relationship). There is now evidence to the contrary, especially if stock abundance is low (Myers and Barrowman 1996). Fisheries usually target the adult stock and can directly reduce the potential for stock increase or recovery. (The more serious problem of reduced per capita recruitment in depleted spawning stocks is considered next under **4.6.2**) Seals, especially harp seals, usually prey on younger fish, although this is less true for hooded and grey seals. Consumption of a number of young fish will have less influence on stock status than removal of the same number of older ones, because young fish must face further mortality before they become mature (and fishable). Removal of a given biomass of young fish, however, may include many more individuals than an equal biomass of adults. In principle, the relative effects of predation mortality can be incorporated in standard stock-assessment analyses, which generally has not been done in Atlantic Canada for a number of reasons detailed below in **4.7-4.11**. We do, where possible, compare estimated numerical removals of fish by seals and fisheries. In section **5** we attempt to estimate the biomass that would be released or removed by various management options.

Some have argued that predation on young fish may reduce competition among survivors, and therefore improve their growth, survival and ultimate fecundity. Although this may seem unlikely in fish stocks that are already greatly depressed, it could apply if the surviving fish remain aggregated so that there is still local competition for food. There is evidence that fish in some collapsed cod stocks are or have been in relatively poor condition (sections **4.7-4.11**), making it difficult to argue that predation has been effective in improving their growth through reducing competition.

4.6.2 The possibility that fish stocks are in a "predator pit"

A general concern is that some greatly depleted fish stocks may be held in a "predator pit" (Walters 1986). This occurs if the proportion of a prey species in the diet of a generalist predator remains constant over a wide range of stock sizes. As a result, the per capita mortality rate suffered by the prey actually increases as its population declines. Examples of this concern are some indications that the proportions of Atlantic cod in grey seal diets off Nova Scotia might not have changed during the 1990s (**4.7.2**) and might even have increased in harp seal diets off Newfoundland (**4.11.5**), despite great declines in cod abundance. However, the statistical power of these time series to detect a true change in seal diets has yet to be ascertained. Severely reduced populations may also show reduced per capita reproductive rates, which in depressed cod stocks in Atlantic Canada could arise from mortality leading to fewer large, fecund females in the population.

Both of the mechanisms described above can result in a negative relationship between per capita rate of increase and population density at low populations, referred to in fisheries literature as "depensation." Myers et al. (1995) concluded from analysis of 128 fish stocks that there is little evidence for this phenomenon. Shelton and Healey (1999) offered an alternative method for statistical assessment, concluding that depensation would be difficult to detect if variability in the stock-recruitment relationship is large and the strength of depensation is unknown. Although Shelton and Healey agreed that the present states of northern cod and harp seal stocks "are conducive to depensation," they also noted that "other explanations . . . need to be given consideration, for example loss of genetic components, continuing fishing activity, and environmental influences." The Panel considers various explanations for failure of cod recovery in each NAFO area (**4.7-4.11**).

4.6.3 The resilience of seal populations vs fish stocks rated "vulnerable"

Harp, grey and harbour seals in Atlantic Canada have increased from smaller population sizes some decades ago, although the very recent status of hooded seals is uncertain (section **2**). On the other hand, the long-term persistence of some marine fish populations has been rated at risk. Indeed, salmon in the inner Bay of Fundy have been declared "endangered" by COSEWIC in 2001, and northern cod was declared "vulnerable" by IUCN in 1996 and of "special concern" by COSEWIC in 1998 (Musick et al. 2000, although this status has been debated, see Hutchings 2000). Three species of wolffishes in Newfoundland waters have recently also been rated as of "special concern." It has accordingly been argued by some that a precautionary approach to such stocks should involve joint management of their predators, such as seals.

4.6.4 Multispecies considerations

It has been argued in some submissions to the Panel that the effects of seals on commercial fish species cannot be understood or predicted, nor can management be implemented, without a thorough understanding of the ecosystems or food webs within which seals and their prey function.

There is no doubt that marine mammals can be important influences in their ecosystems (Bowen 1997). Demonstration that other species are more important as predators of commercial fish species (e.g., Overholtz et al. 1991, Trites et al. 1997) is not sufficient to dismiss the effects of marine mammals. The protocol in UNEP (1999) suggests that a formal "2-way matrix of who eats whom" be established before "deciding which species should provisionally be taken into account in an evaluation of the likely effects of a cull." Some of the information identified by UNEP (1999) as necessary for scientific evaluation of cull proposals requires extensive knowledge of multispecies interactions within which seals and commercial fish species operate [see (iii) and (iv), Table 4.1]. Multispecies approaches, despite many problems, are being actively promoted for fisheries science in general (e.g., ICES 1999), and are part of DFO's sustainable development strategy (e.g., DFO 1997), although total allowable catches (TACs) for exploited fishes in Canada and elsewhere are still largely based on single-species models. In attempting to understand possible effects of seals on fish stocks, the Panel has considered available information on direct influences of other species as well as recent applications of multispecies modelling within each NAFO Division (4.7).

Whipple et al. (2000) provide a useful discussion of the different methodologies that have been used to analyse predation mortality in aquatic ecosystems. We adopt their distinction between static-flow models, dynamic models, and spatially explicit models to structure the following summary.

Static-flow models use mass-balance principles to estimate flows of organic matter or energy among components of an ecosystem using data on diets, estimated assimilation efficiencies, metabolic demands, etc. This can go beyond mere empirical bookkeeping by using models that assume system equilibrium and accordingly "balance" the estimated flows among all components by using Ecopath (Christensen and Pauly 1993) or the more objective inverse-modelling approach (Savenkoff et al. 2001). These models are particularly useful for identifying deficiencies in knowledge of the system. It has to be recognized that Ecosim, as it has been applied, assumes linear interaction terms among components, so that it applies only in conditions close to the assumed equilibrium of the system. It cannot on its own be used to draw conclusions about effects of changes through time from exploitation by fisheries or predation, although by changing the biomass of any component, and re-balancing the system, it is possible to get some insights about effects on others components (see example in 4.7.4). Dynamic models are needed for such predictions.

Most dynamic models of multispecies populations have been extensions of "classical" prey-predator (and competition) models using differential or finite-difference equations. These have been used both to support and oppose the selective removal of one or another living component to influence the abundance or yield of another. Such models were formerly too simple, abstract, or "theoretical" to be of use in reaching conclusions about specific marine mammal/fishery interactions (McLaren and Smith 1985). For example, Flaaten (1988) used models of this kind to conclude (his p. 114) that "sea mammals should be depleted to increase the surplus production of fish resources for man." Yodzis (1994) showed that this conclusion was a consequence of the structure of Flaaten's model, which was based on a few interacting species and linear interaction terms. Models with non-linear interaction terms provided very different conclusions. Yodzis concluded, disappointingly, that "it remains frustratingly difficult to say just what functional form [of interaction] is the appropriate one for a given real population."

Because of the difficulty of specifying all interactions in a system of interest, some have used only those components rated as important in "minimum realistic" models. Perhaps the most oft-quoted example in the context of effects of sea mammals is the three-species model of Punt and Butterworth (1995). They included age-structure in the prey and predator populations, plus cannibalism, in their analyses of the potential effects of an increased harvest of Cape fur seals on the yield of the South African hake fishery. When they assumed that only the one commercial hake species was involved, increasing the fur seal harvest resulted in increased catches. However, when they took account of the fact that there are actually two hake species in South African waters, and that the species preferred by fur seals is a major predator on the species that is predominantly taken by the commercial fishery, they reached the opposite conclusion: an increased fur seal harvest could result in a decreased commercial catch of hake. The applicability of such simplified food-web analyses to cod stocks in Atlantic Canada is discussed in sections **4.7-4.11**.

Other minimum realistic multispecies models have attempted to account for effects of spatial distributions. These include MULTSPEC used by Bogstad et al. (1997, with a more accessible account in Tjelmeland and Bogstad 1998) to investigate interactions between three fishes (capelin, herring, cod), harp seal, and minke whale (*Balaenoptera acutorostrata*) in the Barents and Norwegian sea, and BORMICON (Bjoernsson 1997) to investigate the interactions among Icelandic cod, capelin, shrimp and baleen whales on fisheries yields. Bogstad et al. (1997) tentatively concluded that herring stocks would be reduced by increased whale numbers, whereas increased harp seal numbers would most heavily affect the capelin and cod stocks. These conclusions were generated by removing portions of the model fish and mammal populations and comparing the results with those from a "reference run." They claimed that the results were robust within broad specifications of the interactions.

Yodzis (1998, 2000, 2001a) has cautioned against the usefulness of simplified food-web models. His extended food-web model of the Benguela Current ecosystem, of which the interaction of the fur seal with hakes studied by Punt and Butterworth (1995) is a part, included a wide range of components from bacteria to cetaceans. Yodzis used the model to investigate indirect interactions (for example the effects that fur seals might have on hakes via their predation on other fish species) from changing seal numbers, and to see if valid conclusions can be reached from using only a subset of species in the entire web. The uncertainty of total fish yields following a cull of fur seals in the context of the entire food web was summarized by Yodzis (2001a, Figure 2). He nevertheless concluded that "the qualitative result, that a cull is more likely to be detrimental than beneficial to the total fishery, is robust with respect to underlying assumptions" about the inclusion of other prey effects and shape of the interaction functions. However, the results in Yodzis (2001a) also embodied a substantial probability that a cull of fur seals could have a positive effect on the fishery and contain no valuation of different components of the affected fishery.

Given the enormous difficulties in obtaining enough information for complex, age-structured population models, the only currently plausible dynamic modelling of complete food webs may have to be based on biomasses and the flow of organic matter among components, as modelled statically by Ecopath (see above). Beyond this, the Ecosim software (Walters et al. 1997, Pauly et al. 2000) provides a methodology for investigating the consequences of changes in fishing and predation ecosystems, although its limitations and assumptions must be clearly recognized. In particular, the use of virtual refuges to protect portions of prey from predators does not mitigate all the unnatural mass-action properties of the underlying Ecopath-defined interactions. We review published and ongoing applications of this methodology to Atlantic Canada in sections **4.7-4.11**.

Finally, a recent exchange between Boyd (2001) and Yodzis (2001b) brings out important research in recent years on global-scale environmental shifts and consequent changes in prey-predator and fishery régimes; El Niño is a familiar example. This could raise more uncertainty about the application of complex ecosystem models to particular situations. As we note above (**4.3**), Atlantic Canada may have been subject to just such an event during and after the collapse of cod stocks. However, for specific NAFO divisions (**4.7-4.11**), the Panel believes that negative effects of changes in the physical environment in suppressing stock recovery must be evident in the concrete forms of diminished growth, condition, and fecundity. Otherwise, analysis is submerged in generalities, analogies and abstractions.

Despite all these valuable multispecies approaches, a "common sense" view is that some effects of reducing seal predation in Atlantic Canada are predictable without resorting to multispecies analysis. Given the time lags that may be involved in the re-equilibration of whole systems, a sharp reduction of seal predation on fish of commercial size would indeed immediately increase their availability to a fishery. Similarly, a reduction of predation on pre-recruit fish might give enough short-term relief to permit them to escape a "predator trap," producing sufficient breeding stock to provide continuing release from such a situation. These possibilities are implicitly recognized by Yodzis (2001, p. 80), who notes "on a short time scale we might predominantly observe the effect from the shorter pathway (an increase in fisheries yield), with the contribution of the longer pathway making itself felt only on a longer timescale, possibly leading to a reversal of the response (a decrease in fishery yield)."

4.7 Evidence for the Scotian Shelf, NAFO Divisions 4VsW, 4Vn and 4X

4.7.1 Seal diets and consumption of cod on the Scotian Shelf

The most numerous seals on the Scotian Shelf are grey seals, largely breeding on Sable Island, where there has apparently been a steady increase since the 1960s (**Table 2.1**). Grey seal diets in 4VsW have been assessed from stomach contents collected widely from 1980 and more recently from faecal samples collected on Sable Island (Mohn and Bowen 1996). Bowen and Harrison (1994) calculated that the prey observed in faeces were taken within 78 km of the island haul-out sites, based on the seals' swimming speeds and gut-passage times. They believed these samples best reflected the prey base on the outer, eastern Scotian Shelf (Division 4W), the area of greatest concern in the context of possible impacts on remaining cod stocks. Mohn and Bowen (1996, Table 3) give unweighted all-season mean percentages of cod in "inshore" and "offshore" grey seal samples during 1988-1993 of 21.7% (n=3) and 13.2% (n=10) respectively. Not surprisingly, the differences are not significant, but larger samples might be informative.

The most recent assessments by Mohn et al. (1998, Table 6) summarize the percentage contribution of cod to grey seal diets (wet weights) on the Scotian Shelf in 1971-1998 under three models:

(i) Assuming that cod are a constant proportion in diets gives cod as ~12.6% of consumption throughout the period.

(ii) Assuming that cod in diets varies in proportion to cod abundance yields initial values of ~10-12%, rising to 25+% in the mid-1980s, and falling to ~3% by the mid 1990s.

(iii) A "third scenario, considered more likely than either of the above, was to constrain

> the upper limit of the variable proportion model . . . to a maximum of approximately 20% cod, more consistent with the available diet data." This yields initial and final values close to those of the second model.

The harbour seal was estimated by Hammill and Stenson (2000) to consume mostly herring (427 t per year) and a small amount (100 t) of Atlantic cod in this Division. As very few harbour seals remain on the outer Scotian Shelf (see **2.7.1**), their impact can be ignored.

4.7.2 Cod stock status and possible impacts of grey seals on the Scotian Shelf

With an estimated 1997 spawning stock of 32-37 Kt (DFO 1998a), there is no doubt that cod throughout 4VsW are depressed relative to those in the mid-1980s. Cod spawning occurred widely and strongly, spring and fall, on the Scotian Shelf in the early 1980s, but now occurs mostly on the western end of the Sable Island Bank in fall (Frank et al. 1995). Recent updates (DFO 1999, Branton and Black 2000, Fig. 9) indicate that they are still depressed. The fishery was closed in 1993, but bycatch (and recently a sentinel program) still occur.

The last full cod status report (DFO 1998a), based on Mohn et al. (1998), stated that "seal consumption of cod may be a significant factor inhibiting recovery of this stock." The estimated amount of cod consumed in 4VsW in 1997 was 5.4 or 22 Kt. From an estimated mean weight of cod prey = 201 g (Bowen and Harrison 1994), this might be approximated as 27M-109M young cod from a population of 1+ cod estimated as ~60M individuals in 1997 ((Mohn et al. 1997). The lower consumption value (5.4 Kt, 27M fish) assumes that this has changed in proportion to cod abundance (model 3, above), and leads to the conclusion that "recruitment, even at age 1, has been poor, and that subsequent survivorship to age 3 and 4 has been much less of a factor." The higher value (22 Kt, 109M fish) assumes that cod have been a constant proportion of diets over the years (model 1, above), and "leads to the conclusion that cod stock rebuilding will not likely occur while this degree of predation continues" (DFO 1998a). The latter assumption seems supported by observations that "the proportion of cod in the diet, although variable, has shown no trend over eight years of sampling on Sable Island," although the statistical power of the (unpublished) data to detect such a trend has not been evaluated. In either model, there appears to be a mismatch between the potential availability of cod and the numbers consumed. This is another indication of the uncertainty of the estimates.

The estimated amounts of cod consumed may be compared with estimated sentinel fishery and bycatch landings totaling 231 t in 1997 (DFO 1999), which might be approximated as the order of 100K individual cod from mean weight at age 6 (DFO 1998a) in "commercial" (bycatch) samples.

An updated age-structured model, incorporating interactions among cod, the fishery and seals was presented at the CDEENA Workshop in December 2000 (Fu et al. 2001). Using estimates of fishing mortality and seal-predation mortality on young (1-4 y) and older (5+ y) cod, the residual mortality (M) was estimated for the years 1970-1996. High M in 1982-1984 may have been attributable to discarding. Assessment models that assume constant, relatively low M are likely to overestimate spawning biomass in these circumstances. An observed increase in M for both mature and young cod since 1992 remained unexplained.

The above appears to include qualified circumstantial evidence for a negative influence of grey seals on recovery of cod on the Scotian Shelf. An important caveat comes from fatty acid profiles (unpublished data, S. Iverson and D. Bowen, pers. comm.) of a small number of grey seal samples collected from Sable Island. These profiles suggest that published estimates of proportions of cod in grey seal diets on the Scotian Shelf may be too high.

Recent results of satellite tagging of adult grey seals on Sable Island (D. Bowen, unpublished) show that females largely tend to stay around Sable Island Bank or wander across the eastern shelf and into the Gulf of St. Lawrence, whereas males move largely to the southwestern shelf and beyond (4X). These results could produce some reduction in estimated predation on cod in 4VsW and 4Vn, and its redistribution to 4X and 4T compared with that used by Mohn and Bowen (1996) and DFO (1998a).

4.7.3 Some suggested explanations, other than seals, for failure of cod to recover

Current catches of cod in 4VsW are so small that, unless there is massive under-reporting of bycatches, they are unlikely to explain failure of the cod to recover.

Another possible influence on cod stocks has been an episode of cooling on the eastern Scotian Shelf, beginning in the mid-1980s and continuing into the mid-1990s, with a slow recovery since (Drinkwater 1999). A steady decline in the average condition of adult cod at this time (P. Fanning, DFO, pers. comm.) may have been a result of this cooling, because cod biomass was so low that reduced food availability through intraspecific competition should not have been a problem. This decline may also have produced some of the apparent increase in natural mortality observed at the same time. In 1997, unusually cold shelf-slope waters penetrated to shelf basins, which remain cold at depth. During the late 1990s, however, temperatures increased in the upper 50m (Drinkwater 1999), giving warmer conditions for early development of cod. Finally, "since about 1992, the consistent decline in size at age for all ages seems to have leveled off and some improvements [are] seen," and a sharp increase in cod condition occurred in 1995-1997, although "based on relatively low sample sizes" (DFO 1998a). On this evidence, poor growth and conditions for spawning as a result of oceanographic changes seem unlikely to account for current recruitment failure, although may have done so earlier.

Recent studies of the remnant area of cod spawning on the 4VsW outer shelf over Western Bank in autumn (McLaren et al. 1997) indicated that cod eggs and larvae are retained there through oceanographic conditions. However, they found no evidence of food shortage even for larvae swept off the bank during severe storms.

4.7.4 Multispecies considerations for the Scotian Shelf

Sand lance (*Ammodytes dubius*) is by far the major prey of grey seals on the offshore Scotian Shelf, and is also important for groundfishes. It formed ~67% by wet weight of grey seal diets estimated from samples taken 1988-1993 (Mohn and Bowen 1996, Table 5). Hammill and Stenson (2000, Table 8) estimated that grey seals removed ~89 Kt of sand lance from 4VsW in 1996. A decline in this key species might impact the food base for cod but, because of its burrowing habits, sand lance stocks are difficult to assess. However, as noted above (section **4.4.3**) there is no evidence in body condition for a current shortage of food for cod.

High predation on cod eggs and larvae might also explain the continuing poor recruitment of cod. Negative relationships between cod recruitment and abundance of herring (*Clupea harengus*) and mackerel are well known in some North Atlantic areas, and suggested explicitly for the southern Gulf of St. Lawrence (Swain and Sinclair 2000; as discussed below, **4.8.3**). Harris (2000) stated that: "herring and mackerel are known to consume fish larvae in many ecosystems yet there is a notable absence of larvae in the stomach samples" (from the Scotian Shelf), suggesting "that they would be seen rarely because of the speed at which they are digested." Yet fish eggs have been found in these stomachs. Hunter and Kimbrell (1980) showed that anchovies digest their eggs rapidly, yet they found a strong positive relationship between numbers of eggs in guts and abundance of eggs in field samples. It is also true offshore RV surveys in July 1999 found herring to be "the highest in the 17 year time series where the same vessel and gear have been used" and "widely distributed on banks west of Sable Island" (DFO 2000a). The time series (DFO 2000a, fig. p. 6), however, shows an increase beginning 1994-1995, a falloff in 1996-1997, and a large increase 1998-1999. The resurgence has therefore occurred some time after cod stocks and recruitment diminished. Finally, there is some evidence (C. Taggart, pers. comm.) that disappearance rates of cod larvae around Western Bank in autumns 1997 and 1998, could be largely accounted for by water mass dilution. Evidence that offshore cod stocks in 4VsW have not recovered because of predation by pelagic fishes on their eggs and larvae does not seem compelling, although herring may now pose a problem.

Since it has been suggested that seals may benefit cod recovery by preying on such pelagic predators (see below, **4.8.3**), we also note that neither herring nor mackerel have apparently been found in diets of grey seal in the offshore Scotian Shelf (Mohn and Bowen 1996, Table 5), although these were from samples obtained before the recent increase in offshore herring. The predominance of the two pelagic species in inshore diets (Mohn and Bowen 1996, Table 5) indicates that they are clearly detectable when consumed.

Broader consideration of grey seals in the ecosystem context of 4VsW is currently being explored in a program on Eastern Scotian Shelf Integrated Management (O'Boyle 2000). Two approaches have been applied to the 1980s period, prior to the major collapse of cod stocks (Bundy et al. 2000b). An unpublished Ecopath analysis of the 1985-1987 pre-collapse situation (as presented to the Panel by P. Fanning, 26 June 2000) concluded that grey seals accounted for roughly 5%, adult cod another 28%, and other predators 15%, leaving 48% of total juvenile mortality (total M = 1.08) unexplained. As noted in **4.7.2** a plausible cause of unaccounted-for mortality during that pre-collapse period is discarding, although not applicable at present, with cod catches greatly reduced and discarding therefore minimal.

Further food-web approaches to 4VsW were discussed in the CDEENA 2000 Workshop at Bedford Institute (Fanning 2000). For example, from recent NOAA surveys extending to the Scotian Shelf, cetaceans may be more important fish predators than grey seals (A. Bundy, DFO, pers. comm.). Mohn (2000) presented a prototype of a minimum realistic, multispecies model at this workshop. This age-structured model used six species groups based on their importance as food or predators (grey seals and whales combined) of cod in the Ecosim analysis (above). Mohn concluded "bottom-up effects (decreased cod condition affecting survivorship and reproduction) were much less important than predation effects."

Finally, Ecosim has recently been used to project from the mid-1980s to the present (A. Bundy, DFO, pers. comm.). The preliminary results indicate that the cod stock in 4VsW should have recovered to pre-collapse levels, even though cod were taken as 17% of grey seal diets in the initial food web (per the third model of Mohn et al. 1998; see above, **4.7.1**).

The ongoing, admittedly tentative, multispecies models thus generally do not appear to support seal consumption as "a significant factor inhibiting recovery of this stock" (**4.7.2**) in 4VsW. Clearly more information will be needed before firm conclusions can be drawn from such analyses.

4.7.5 The situation in 4Vn and 4X/5Y

The northern extremity of the Scotian Shelf has traditionally been treated as a separate management unit, 4Vn, because it both has a resident inshore cod stock, and receives wintering migrants from 4T. It has not been exploited except through sentinel surveys and a very small bycatch since late 1993. The latest full reports (DFO 1998b, 2000b) picture stocks that are similarly depressed to those of 4VsW, with apparent natural mortality exceeding that traditionally assumed in fisheries management. Although seals are not mentioned as a possible cause of this mortality, grey seals from the Sable Island and southern Gulf populations both occur there in numbers (Hammill et al. 1999b, Figures 5, 6). Summer RV surveys (preliminary maps and graphs in Branton and Black 2000) indicate that 4Vn cod remained depressed in 2000.

Cod stocks in the southwestern Shelf and Bay of Fundy (NAFO Div. 4X/5Y), where grey seals were once thought to be outnumbered by harbour seals, appear to be less depressed. The 2000 RV surveys (reviewed in Branton and Black 2000, DFO 2000b) indicate continuing low biomass, but a recruitment potential (age 2 fish) that "appears better than in recent years, but still below average for the RV series" (DFO 2000b). Although fishing mortality has dropped, it is still over the target $F_{0.1}$ level. Even under this situation, the stock biomass was predicted to increase in 2001. It is noted by DFO (2000b) that "low catches in the survey in recent years, however, is grounds for concern and suggests increased mortality from other sources." No mention of seal predation is given, although grey seals (especially large males) are now known to spend more time than once thought in Div. 4X/5Y, as indicated from satellite tagging (see **4.7.2**). This Division may also still be plagued by under-reported and unreported discarding of cod (Breeze 1998).

4.7.6 Possible impacts of grey seals on other Scotian Shelf stocks

An indication of the relative importance in grey seal diets of commercial groundfish species other than cod in offshore 4VsW is in Mohn and Bowen (1996, Table 5). Among species contributing >5% in wet weights in three inshore collections were: pollock (*Pollachius virens*), with 7% in summer 1988-1990, and flatfish (spp.?), with 14.6% in summer 1992. Offshore, only flatfish contributed more than 5% of average diet samples, ~9% across all years, 1988-1993. Silver hake (*Merluccius bilinenaris*), apart from an anomalous 25.8% in an offshore collection from summer 1988-1990, consistently made up only 0.1-5% in another nine collections. The most recent stock status report for the above groundfish stocks on the Scotian Shelf (DFO 2000c) has pollock remaining scarce throughout, western Scotian Shelf flatfish showing "stability in stock status in recent years about the long-term mean," while "biomass for silver hake remains very low and total mortality is high." Thus, there is no obvious relationship between the (small) proportions of these species in seal diets and status of their stocks.

4.7.7 Sealworm on the Scotian Shelf

Another impact of grey seals on the Scotian Shelf is through their role as the definitive host of the sealworm, *Pseudoterranova decipiens* (Bowen 1990), which also infests the flesh of groundfishes, notably cod and the American plaice, *Hippoglossoides platessoides*. The latter fish has been used in tracking the parasite in fillets since 1980 by McClelland et al. (2000) and McClelland and Martell (in press). Prevalence and abundance are greatest in fish collected from the central Scotian Shelf (4VsW) near Sable Island, although the west coast of Cape Breton Island, northeastern New Brunswick, and the mouth of the Bay of Fundy also have high levels. Although both prevalence and abundance were stable or declining 1989-1993, possibly from the impact of colder bottom waters on the parasite's hatching, early development, and transmission rates, both are again increasing at most Maritimes sampling sites.

Fish plant managers and workers in Nova Scotia fish plants have spoken convincingly of increases of sealworm in cod in recent years in places where worms were once scarce. One representative (D. Garrison, President, Sambro Fisheries Ltd., in litt. 26 Sept. 2000) measured this change as follows: "In 1990 the ratio of fish cutters to wormers was one wormer to two cutters. In 2000 it is a bit more than reversed . . . Ten years ago we were seeing one or two per filet. Today it is more like 6 or 8 worms per fillet."

4.7.8 Summary assessment for the Scotian Shelf

Although estimated consumption of cod by grey seals considerably exceeds that taken by humans, these estimates have high uncertainty, and the overall evidence that grey seals may be preventing recovery of stocks on the Scotian Shelf is weak and dependent on model assumptions. Also, new techniques of estimating seal diets and new information on seal distribution will probably reduce present estimates of cod consumption in the core cod spawning area of Western Bank.

There is no indication that adverse oceanographic conditions are now negatively affecting cod body condition, and therefore survival and reproduction.

Other species within the Scotian Shelf food web might also influence cod recovery. Offshore herring have increased too recently to explain earlier failures of cod recruitment, but could pose a new problem. Recent surveys have found more (fish-eating) whales than formerly supposed. A simplified food-web analysis concluded that top-down control (predation by grey seal plus whales) of cod populations is more likely than bottom-up control (through food availability). A preliminary Ecosim model of the pre-collapse food web suggested that cod should have recovered, despite seal predation.

There is little information with which to judge the effects of seals on cod in 4Vn, where stocks remain depressed, or 4X5Y, where stocks may be somewhat healthier. More grey seals occur in the latter Divisions than previously assumed.

There is no firm evidence to link seals with the lack of recovery of other groundfish species in 4VWX and 5Y.

Prevalence and abundance of sealworm in groundfishes have increased on the Scotian Shelf since 1993.

4.8 The southern Gulf of St. Lawrence, NAFO Division 4T

4.8.1 Seal diets and consumption of cod in the southern Gulf

Although harp seals breed in the southern Gulf, cod have largely left the area when the seals arrive, and the seals feed little before leaving. Hammill and Stenson (2000, Table 8) do not include any consumption by harp or hooded seals in their figures for 4T. Hammill et al. (1999b) offered "a very rough estimate" that harp seals consume annually some 2 Kt of fish, whereas Hammill and Carter (2000) estimated cod consumption at 200 t (95% CI of 0-500 t). There is little information on diets of the small group of hooded seals that breed in 4T, the diet of which has been based on Newfoundland samples (Hammill et al. 1997); their consumption is attributed to the northern Gulf Divisions 4RS by Hammill and Stenson (2000, Table 8). Harbour seals are considered to be too uncommon to have an important impact (Hammill et al. 1999b). Consumption by these three species is thus minor relative to that of the grey seal, to which Hammill and Stenson (2000) attribute 99% of prey consumption in this Division.

There is much exchange between the population of grey seals breeding in the Gulf and that breeding on Sable Island. We consider the most recent estimates of annual pup production by grey seals in 4T elsewhere in this report (2.5.3). Compared with the Scotian Shelf, consumption estimates are relatively poor because of limited sampling and poor information on seasonal patterns of distribution. Hammill and Stenson (2000) present a single mean estimate of 7,235 t of cod for 1996. Consumption of cod in 1999 was given as "on the order of 5000 to 13000 tonnes" by Hammill et al. (1999b), and was not translated into numbers at age. A more recent assessment by Hammill and Carter (2000) stated that cod consumption had increased from 1000 t in 1984 to 2500 t in 1996, and with a slight decline in estimated grey seal numbers in the Gulf was "just over" 2000 t (95% C.I. 0-10,000 t) in 2000. These estimates should be the best available, as they were "based on actual diet data (vs an assumed diet; Hammill et al. 1999)." With these confidence intervals, the estimate must be treated cautiously. Assuming the cod are similar in size to those taken by grey seals on the Scotian Shelf (average 0.2 kg), the biomass estimate translates to ~10M fish.

4.8.2 Cod stock status and possible impact of seals in the southern Gulf

The recent status of cod in the southern Gulf is summarized in DFO (2000c and 2001b). Figures for 2000 in DFO (2001b) indicate a spawning biomass slightly less than 100 Kt and an abundance of somewhat fewer than 200M age 3+ fish, reflecting a decline of RV catch per tow of almost 30% since 1999. Sinclair (2001) detailed an apparent shift of natural (adult) mortality (M) from M = 0.2 in the 1970s to M = 0.4 in subsequent years. Natural mortality in 1999 was rated as: "may be declining" (DFO 2000c), but this optimism was not borne out by 2000 analyses that "continue to indicate values in the range of 0.4 in recent years, more than twice historical values" (DFO 2001b). Causes "would include all sources of unaccounted mortalities such as poor environmental conditions, predation, unreported catches . . . decline in growth rate" (DFO 2001b). Assuming the average weight of fish caught to be ~2 kg, the 1999 and 2000 fisheries each caught (given small unreported catches) ~3M cod. Risk analyses for 2001 projected that, unfished, the 2001 spawning stock would decrease by 1%, but with a fulfilled TAC of 6 Kt, would decline by more than 5% (DFO 2001b).

The possible causes for this gloomy situation bear more thought. The recent decline reflected survey estimates of numbers of 2- and 3-y-old cod that were "near the lowest values observed" (since 1971; DFO 2001b). This evidently does not reflect poor per capita recruitment, which has been relatively high in the 1990s, although not as high as in a previous low abundance period in the late 1970s. Neither the fisheries take of roughly 3M recruited fish nor seal consumption on the order of 10M of mostly pre-recruits would seem to be high for a normal cod population of almost 200M recruited fish. Unless there is a serious seasonal bias in seal sampling, or they kill many large cod without evidence of hard parts (see the issue of "belly feeding" in section **4.11.7**), there appears to be no evidence that grey seals are responsible for high natural mortality of cod in the southern Gulf.

4.8.3 Multispecies considerations for the southern Gulf

An important hypothesis developed by Swain and Sinclair (2000) is that abundance of herring and mackerel in the southern Gulf affects the recruitment of cod through predation of cod eggs and larvae. Swain and Sinclair suggest that, because of this, seals may "have an indirect positive effect [on cod stocks] through predation on pelagic fishes." Indeed, their title suggests that they believe the argument might apply more widely to "the cod recruitment dilemma in the Northwest Atlantic." It is true that mackerel and herring are known elsewhere to consume eggs and larvae of cod and have been suggested to influence cod recruitment (references in Swain and Sinclair 2000). The one reference for herring in the Gulf of St. Lawrence (Messieh et al. 1979) is uninformative on proportions of cod among fish eggs (in 11% of stomachs) and larvae (a "trace") eaten. (See **4.7.4** for consideration of bias from rapid digestion of such eggs.) However, there is plausible opportunity for herring and mackerel during their heavy feeding period in summer to consume cod eggs and larvae.

Problems attending analysis of incomplete food webs have already been noted (**4.6.2**). It is nevertheless possible to consider individually the proposed interacting components in the southern Gulf of St. Lawrence. The herring spawning biomass estimates used by Swain and Sinclair (2000) are the generally accepted ones used in stock status assessments. The mackerel spawning biomasses are half the SPA estimates for the entire Northwest Atlantic stock, within which the "northern" (Gulf) and "southern" (New England) spawning components are "believed to be of similar size." These SPA results are from NFSC (2000, Table D13), wherein there are warnings that "none of the model runs [that produced] these data were acceptable" and that the tabulated data were for "illustrative purposes only" and "not to be cited." Although the NFSC time series used by Swain and Sinclair (2000) do not agree with the spawning biomass trends for 1983-1996 based on egg surveys in the Gulf of St. Lawrence (Grégoire et al. 1997), the latter themselves are prone to errors related to timing of the surveys in relation to times of mackerel spawning. The longer NFSC (2000) time series, including the 1970s when biomasses of pelagic fishes were low and cod recruitment very high, could be viewed as the better choice.

The role of seals in this "triangular food web" is less certain. An estimated 3000 t of herring were consumed by grey seals in the southern Gulf in 2000 (with very wide limits per Table 3 in Hammill and Carter 2000). This apparent consumption is very minor when set against age 4+ biomasses of ~49 Kt for the spring spawning component and 415 Kt for the fall spawning component of herring, and compared with a combined fishery take of ~76 Kt (DFO 2001c). Consumption of mackerel was not given by Hammill and Carter (2000), but they did estimate that mackerel supplied only ~4% of the herring contribution to diet energy of grey seals (their Table 3). Taking individual herring and mackerel as energetically equivalent, this translates to ~120 t of mackerel. This seems inconsequential from a spawning stock biomass (taken as an index) of ~2M t in 2000 by Swain and Sinclair (2000, their Fig. 1), or even from the smaller current estimate of 366,022 t in DFO (2001d). The modest grey seal predation on what seem to be enormous resources may be related to geographical and temporal mismatch between the seals and the two pelagic fishes (M. Hammill, DFO, pers. comm.). There might also be suspicion if otoliths of these fishes were subject to greater rates of erosion by digestion. However, their presence in some seal stomachs, and even predominance in inshore diets in Nova Scotia (section **4.7.4**), indicate that mackerel and herring are fully detectable when consumed.

Thus, whereas Swain and Sinclair's (2000) hypothesis of a negative effect of pelagic fish biomass appears generally convincing, an indirect positive role of seals does not appear to be so.

4.8.4 Possible impacts of seals on other southern Gulf stocks

Small amounts of winter flounder (*Pseudopleuronectes americana*) and yellowtail flounder (*Limanda ferruginea*) were estimated to be consumed by seals in the southern Gulf by Hammill and Stenson (2000, Table 4). Larger estimates in Hammill and Carter (2000) are based on local sampling, but great differences among the five sample localities and seasons produce very broad standard deviations, encompassing zero. Based on very variable samples from 4T, Hammill and

Carter (2000) estimated that 15 Kt of winter flounder were consumed by grey seals in 2000, but did not list them in harp seal diets. The stock biomass of winter flounder in 4T is roughly 8 Kt (or double that, allowing for catchability, per A. Sinclair, DFO, pers. comm). RV catches in 2000 increased over those of the previous four years, but with much local variability (DFO 2000c). This species has become more valued as bait and in a limited food fishery (DFO with catches totaling 600 t in 2000

Very little yellowtail flounder was found in grey seal samples, but from the listed energy contributions of this species and cod (Hammill and Carter 2000, Table 4), harp seals can be estimated to have consumed very roughly 31 Kt of this species. The estimated stock of yellowtail flounder is small (4 KT or 8 Kt corrected for catchability, per A. Sinclair, DFO, pers. comm.), with signs of improved recruitment 2000 (DF0 2001b). There was an estimated fishery take (mostly for bait) of ~300 t.

It is obvious that the above-estimated consumptions (mostly smaller fish?) by seals exceed the estimated stock sizes of the two pleuronectids. The very large uncertainty of estimates should be borne in mind. There may also be bias in the consumption estimates from the fact that both fishes are most common close to shore, i.e., close to where seal stomachs have been sampled, and accordingly could be over-represented in estimated diets (A. Sinclair, pers. comm.).

The white hake (*Urophycis tenuis*) in 4T has been under moratorium since 1995, with some bycatch, sentinel-survey, and recreational removals. Population numbers, and to a lesser extent biomass, have increased recently with increasing recruitment, but estimated natural mortality has risen (DFO 2001e). The consumption of white hake by all seals in 4T was estimated at a mere 35 t in 1996 by Hammill and Stenson (2000, Table 4), but this is considerably exceeded by the estimate of 5000 t (without C.I.) by grey seals alone in Hammill and Carter (2000). Silver hake is included as supplying 1279 t to seal diets in 4T by Hammill and Stenson (2000), but is not listed for grey seals in Hammill and Carter (2000), although they included "hake" as an estimated 1% of harp seal diets.

Some 15 Kt of snow crab were removed by the fishery in 2000 (DFO 2001f). Hammill and Carter (2000) noted some consumption of snow crab by harp seals in 4T, offering two estimates for 2000, based on locally very variable samples, of 1000 t (95% Confidence Interval, 0-4000 t) and 2500 t (0-6500 t).

Despite the large, but probably unrealistic, estimates of seal predation, stocks of the three fish species appear to be showing improvement. However, there is concern about localized gear damage and consumption by seals of both winter flounder and white hake overwintering in P.E.I. estuaries (D. MacEwan, P.E.I., Department of Fisheries and Aquaculture, and F. Beairsto, P.E.I. Fishermen's Association, pers. comm.). Grey seal diets have not been assessed in these places, according to sample sites listed by Hammill and Carter (2000). The possible impact of harp seals on snow crab stocks in 4T cannot be adequately assessed, especially without estimates of the proportions of female crabs in the diet samples.

4.8.5 Summary assessment for the southern Gulf

Although estimated amounts of cod in grey seal diets are very imprecise, the small estimated consumption relative to cod stock biomass does not seem to implicate seals in the present high adult mortality rate and lack of recovery of cod in the southern Gulf.

The present abundance of herring and mackerel in the southern Gulf may be a factor in poor cod recruitment relative to the 1970s, but grey seals evidently consume too few herring and mackerel to support the hypothesis that they may control predation by those pelagic fishes on cod eggs and larvae.

Stocks of winter flounder, yellowtail flounder and white hake are apparently showing some signs of improvement, notwithstanding high levels of estimated consumption by seals. These estimates have extreme variances and may be biased, so better estimates are needed. There is local concern about consumption of winter flounder and white hake in P.E.I. estuaries. The apparent take of snow crab by harp seals is low relative to estimated crab stocks and fishery removals.

4.9 The northern Gulf of St. Lawrence, NAFO Divisions 4RS and 3Pn

4.9.1 Seal diets and consumption of cod in the northern Gulf

Diet estimates from the northern Gulf have sometimes explicitly included estimates from NAFO Div. 3Pn, and sometimes not. Stenson et al. (1997b) estimated that seals of all species in 4RS and 3Pn consumed 28 Kt of Atlantic cod in 1981, and 54 Kt in 1994, with 95% confidence limits for the 1994 estimate of 14-102 Kt. There has been some refinement of estimates since that time.

Harbour seals in 4RS in 1996 consumed an estimated 100 t (Hammill and Stenson 2000, Table 8), and hooded seals 107 t (their Table 8), although the precise value for the latter depended on what natural mortality rate was used. A range of 68-101 t in 1995 was provided by Hammill et al. (1997, Table 5). Relative to the consumption by grey and harp seals, consumption by harbour and hooded seals can be ignored.

Most grey seals breed on Sable Island and in the southern Gulf, and some of these feed in 4RS and 3Pn, mostly during April-December (Hammill 2000, Table 2b). Hammill and Stenson (2000, Table 8) estimated the 1996 consumption of cod by grey seals in 4RS alone as 13,803 t. Hammill (2000, Table 6) provided another estimate of 11,693 t (based on the average proportion of cod in the diet minus 1 standard error). Accounting for the estimated interim growth of the grey seal population yielded a consumption of 14,470 t in 1999; this was also expressed as 467 t (~5M individual cod) ages 1-2 and ~14,003 t (~19M individuals) ≥3 y old.

Some harp seals pup along the Québec North Shore, but more forage in 4RS before and after the pupping season. Hammill and Stenson (2000) estimated that harp seals in 4RS in 1996 consumed 42,089 t of cod, with none attributed to 3Pn. Hammill (2000, Table 7) gave lower estimates of 22,416 t in 1996, or 22,496 t in 1999. This change resulted from more realistic assumptions about the relative disposition of the seals between 4R and 4S, the latter with a higher proportion of cod in diets. This was also given as 4,220 t (~133M fish) ages 0-2 plus 18,276 t (~49M fish) ≥3 y old.

For further understanding of the role of seals in the northern Gulf, there is a need for increased sample sizes to refine estimates of diet, and better information on the way in which harp seals divide their time among the Divisions and Subdivisions.

4.9.2 Cod stock status and possible seal impacts in the northern Gulf

Possible impacts of seals in 4RS and 3Pn also have to be evaluated in the light of cod migrations to and from those areas. The most recent stock status report (DFO 2001g) noted "that a significant proportion of the cod caught in winter in areas 3Psa and 3Psd were incursions of Gulf cod," and examined effects of allocating 75% of that catch to the northern Gulf stock.

Because of extreme reduction of the cod stock, the fishery was closed in 1994 and reopened with a small quota in 1997. The 1999 fishery catch was 6,683 t. Indices of stock size based on RV surveys and sentinel fisheries increased in 2001 (DFO 2001g). Estimates of stock size (of fish more than 3 y old) from Sequential Population Analysis continued to increase from a low of 31 t (50M fish) in 1994 to 95 Kt (98M fish) at the beginning of 2001. However, these values are far below the estimated 610 Kt (537M fish) in 1983.

Because of apparent negative environmental effects on cod condition, formerly wasteful fishing, and growing predation, it was decided in 1998 to increase the value assumed for natural mortality (M) from 0.2 to 0.4, and this has been maintained in the current stock assessment, since "predation by seals continued to increase until at least 1996" (DFO 2001g). There is good evidence that low energy reserves led to low fecundity (Lambert 2000) and high mortality during the 1990s, presumably reducing the potential for stock recovery. The physical (or trophic) environment is no longer as hostile. "In general . . . condition indices for cod have improved since the early 1990's . . . and now reflect a good and stable condition." Mean weights of 6-y-old fish, for example, have been above the long-term mean since 1997 (DFO 2001g, Fig. 3).

Despite improved environmental conditions and controlled fishing, the predictions are for slow recovery at best. "A 10% target level for growth of adult biomass would only be achieved by reinstituting the moratorium" (DFO 2001g). Although the stock has shown a modest increase in recent years, the conclusion that seals are important predators of cod in the northern Gulf appears to be inescapable.

4.9.3 Multispecies considerations for the northern Gulf

Savenkoff (2000) has used inverse modelling to "balance" the estimates from a variety of sources of the productions and flows of organic matter among species or species groups in the Gulf of St. Lawrence during 1985-1987. From this, it was estimated that seals were responsible for 29% and large cod 50% of cod mortality. An ongoing dynamical system analysis (K. Savenkoff, DFO, pers. comm.) could be more pertinent to the current situation (cf. **4.11.6**).

4.9.4 Possible impacts of seals on other northern Gulf stocks

Estimated total consumption by all seals of Greenland halibut in 4RS was estimated as 3,913 t in 1996, most of which was attributed to hooded seals (Hammill and Stenson 2000, Table 4). Consumption of American plaice was estimated to be 1,214 t, yellowtail flounder 967 t, and Pleuronectidae 72,706 t. The relative proportions of commercial flatfishes in the last group are not estimated, but more than half of identified flatfish biomass was non-commercial windowpane. Total consumption of Redfish (*Sebastes* spp.) was 97,002 t almost all of which was consumed by harp seals (Hammill and Stenson 2000, Tables 4 and 8).

A more recent analysis (G. Stenson and E. Perry, pers. comm.) of samples from ~30 hooded seals from the Newfoundland west coast (4R) found no traces of Greenland halibut or Pleuronectidae. In this analysis, redfish were estimated to supply ~58% of diet energy of hooded seals. Although thought to be scarce in 4R, hooded seals are more common in 4S (G. Stenson, DFO, pers. comm.), and their consumption of redfish in the combined 4RS could be more important than suggested by Hammill and Stenson (2000, Table 8).

Annual fishery catches of ~300 t Greenland halibut in 4RST in recent years (DFO 2001h) are less than a tenth of the above-estimated consumption by hooded seals in 4RS, and neither has apparently prevented considerable increase of this fish during the 1990s (DFO 2001h, Fig. 6, 8). A small fishery for witch flounder occurs in 4RST, where the biomass appeared to increase sharply in 1999 (FRCC 2000). There are no recent assessments of other Pleuronectidae with which to compare the estimates of seal consumption. Redfish, which are depleted and for which "the prognosis for this [entire Gulf] stock remains poor for the foreseeable future" (DFO 2000d), and the large consumption by seals could be of concern.

4.9.5 Summary assessment for the northern Gulf

Recent estimates of consumption of cod by seals in this area are substantial; although the variance is not given, it must be high. The large consumption of 3+ y fish is one reason for the use of a high estimate of natural mortality rate (M = 0.4) in recent stock assessments. Despite curtailment of "wasteful fishing" and improvement of cod condition, cod stocks have only increased very slowly. The conclusion that seals are important predators on cod in this area appears to be inescapable.

Among other commercial groundfish species, Greenland halibut and unspecified Pleuronectidae are estimated to be very large components of seal consumption. The stock of the former is increasing, but the status of the latter (partly non-commercial species) is largely unknown. Depleted redfish stocks are also very important in seal diets, and may be even more so if recent estimates for hooded seal in 4R prevail throughout 4RS.

4.10 Southern Newfoundland, NAFO Subdivision 3Ps

4.10.1 Seal diets and consumption of cod in southern Newfoundland

Stakeholders and others pointed out to the panel that the only cod stock in Atlantic Canada that had apparently shown relatively quick population recovery was in 3Ps, which was also the only NAFO area they believed not to have large numbers of seals. However, this view may reflect lack of information, as harp seals are regularly caught there in lumpfish nets (Walsh et al. 2000), and some satellite-tagged grey seals and hooded seals are known to have spent time in 3Ps, although the latter did not appear to stay long (G. Stenson, pers. comm.).

Hammill and Stenson (2000, Table 8) estimated that 9,887 t of cod were consumed by grey seals and 34 t by harbour seals in Subdivision 3Ps and Division 4X (the western Scotian Shelf and Bay of Fundy) combined. They do not attribute any consumption to harp seals in these areas, although Stenson et al. (1997, Table 4) listed percentage wet-weight estimates for "Newfoundland SW Coast" (Atlantic cod 13.2%, capelin 28.4%, arctic cod 10.1%), by which is meant mostly 3Pn with parts of 4R south of St. Georges Bay (G. Stenson, pers. comm.). Given the known abundance of grey and harbour seals in 4X, these limited data support the general belief that seal consumption has been *relatively* low in 3Ps compared to other Divisions and Subdivisions.

4.10.2 Groundfish stocks and possible seal impacts in southern Newfoundland

The dynamics of cod stocks in 3Ps are complicated by the fact that portion of the stock migrates along coastal Newfoundland into coastal 3L and beyond into 3K during summer. Fish from a mixture of stocks occur on Burgeo Bank, within 3Ps, but genetic analysis has suggested that the proportion of inshore cod from Placentia and Fortune bays (in 3Ps) on Burgeo Bank is "small to negligible" (Ruzzante et al. 1999).

The most recent stock status report (DFO 2000e) notes problems in assessing the 3Ps cod and concludes that, despite previous optimism, there has been a "downward trend in 3Ps spawner biomass in recent years." It recommends a very precautionary approach to estimating TACs. DFO (2000f) makes no reference to predation as an issue. Shelton (2000) noted that 3Ps cod showed evidence of depensatory population growth, but did not mention seal predation as a possible cause.

A recent overview of other groundfish species in 3Ps (DFO 2000f) dealt with small, geographically marginal populations of haddock (*Melanogrammus aeglefinus*) and pollock, and larger stocks of American plaice (*Hippoglossoides platessoides*), witch flounder and white hake. American plaice remains well below 1980s levels, the witch flounder exhibits relative long-term stability, and the hake appears to be increasing substantially in its wider stock range. None is tabulated as "important prey" of seals in Hammill and Stenson (2000, Table 8) although, in the latest diet data presented for the groundfish assessment, American plaice and Pleuronectidae were a larger component than previously recognized (G. Stenson, DFO, pers. comm.).

4.10.3 Summary assessment for southern Newfoundland

The assumption that consumption by seals has been relatively low in 3Ps is not based on much sampling, but appears to be plausible, although the panel has no new evidence on the subject.

The latest assessment notes a downward trend in cod stocks, but seal predation has not been suggested as a cause of this trend or of apparent recruitment depensation.

The status of and prognosis for other commercial groundfish stocks are inconsistent, and none is rated as important prey of seals.

4.11 Eastern Newfoundland and southern Labrador, NAFO Divisions 2J3KL

The very core of controversy about the interaction between seals and fisheries, and the most complex issues concerning seals, are in relation to their possible impacts on the remnant stocks of northern cod off Newfoundland. The reasons for the collapse of the stocks have been widely discussed and sometimes disputed; a short, thoughtful review is by Shelton and Lilly (2000). We have taken the Panel's mandate as dealing only with the possible role of seals in the present state of the stocks and their lack of recovery. Because of voluminous information and strong views on these subjects, this section is longer than were those on other NAFO Divisions and Subdivisions. Little can be said about the southern Grand Banks, Divisions 3NO, except that there is recent evidence of modest increase of cod there (Lilly et al. 2001; NAFO 2001). Nothing quantitative appears to be known of seals in 3NO, although stakeholders have reported increased sightings and some satellite-tagged harp seals went there during 1995-1997. We do not attempt to review information from those Divisions.

4.11.1 Earlier views of what was needed to improve understanding

A series of recommendations made in early 1997 by an international workshop on interactions between harp seals and the fishery (CCFI 1997) is a useful gauge of subsequent work. These recommendations are paraphrased below, along with brief indications of what has been done to fulfil them. We deal more extensively with this subsequent work in sections that follow.

> 1. There is a need for estimates of abundance and distribution of pre-recruit cod, age 0-2 y, in inshore and offshore 2J3KL from existing RV survey data, and from a "dedicated survey" to provide more precise information.

There are still no reliable estimates of the abundance of these age classes. It is regrettable that the only dedicated program to obtain estimates of inshore 0-age recruitment was cancelled in 2000. We deal with recruitment to fishable stocks under **4.11.2**.

> 2. "There is [a] need for better estimates of consumption of fish by other predators in the

> ecosytem . . . to refine the estimates of biomass transfer between all the important components of the Newfoundland-Labrador shelf ecosystem."

Some progress has been made using data from the 1980s (see **4.11.6**).

> 3. ". . . to extend the single species models used to assess the status of cod stocks to include the effects of other predators."

Some progress has been made with multispecies modelling using the Ecopath and Ecosim packages (see **4.11.6**).

> 4. More harp seal diet sampling and satellite-tag deployment are needed to ensure that samples are representative, especially of the times spent inshore and offshore in 2J3KL.

We give updated information under **4.11.4**. However, diet sampling is still highly unrepresentative, with proportionately few samples from offshore areas, where harp and hooded seals are believed to spend more than 80% of their time. Substantially more information on seasonal distributions is needed. Almost nothing is known of the movement of immature seals, and the adult data are from only two years during the mid-1990s.

> 5. "Existing information on the proportion of cod in diet of harp seals . . . should be re-analysed to determine the statistical power of these data to detect trends over time, and to estimate the probability that this proportion has fallen . . . in recent years."

Although the existing information has been re-analysed and estimates improved with some support from the panel, there has been no formal analysis of trends in these data.

> 6. Abundance, trends, and replacement yields for harp seals should be re-estimated.

The most recent analyses have been dealt with in section **2.3.1**.

The workshop (CCFI 1997) also supported continuing efforts to estimate capelin biomass in these divisions. We consider the status of capelin in section **4.11.6**.

4.11.2 The complex structure of cod stocks in eastern Newfoundland

The situation in 2J3KL is complex, and not well reflected by the use of broad management units of NAFO Divisions. Myers et al. (1997b) recognized four types of subpopulations: (1) bay stocks, spawning and overwintering in deep bays; (2) headland stocks, overwintering in deep water off headlands; (3) offshore migrants, wintering at the shelf break and migrating inshore to feed in summer; and (4) offshore residents. Another summary of former and current distributions of putatively or demonstrably distinct cod spawning stocks is in Smedbol and Wroblewski (2000). Further general information is in the most recent northern cod stock status reports (DFO 2000g, 2001i), some of it detailed in Lilly et al. (2001).

There has been little or no recovery of northern cod stocks since their collapse and the 1992 moratorium. No significant concentrations were found in 1996-1998 offshore RV surveys to 1500 m. Those spawning on Hamilton Bank, and on Belle Isle and Funk Island banks, collapsed by the early 1990s, leaving small numbers of spawners offshore. In 1999, these offshore cod "remained broadly distributed at very low density in autumn" (DFO 2000g). Spawning was observed in 1994 in one small concentration in Hawke Channel, off southern Labrador, but little has been seen there since.

A more detailed view of local cod spawning areas in Notre Dame and Bonavista bays was based on surveys of fishermen's knowledge of fish in spawning condition (Potter 1996). Although "bay cod" in SE Newfoundland had long been recognized, they became a research focus in the mid-1990s, when a large aggregation was detected in Smith Sound, on the west side of Trinity Bay. Since then, the situation has been expressed in the recommendation "that information on stock status should be provided for the inshore and offshore separately" (this and subsequent quotes are from DFO 2000g). The structure of the inshore stocks is complex. In winter 2000, "a large and dense aggregation of cod was found in Smith Sound," whereas "from western Trinity Bay to Western Notre Dame Bay [there were] no other aggregations anywhere near [that] size." Tagging studies in 1999 indicated that these inshore cod are resident, with "considerable movement among [the] bays." In addition, tagging indicates that some offshore and inshore cod from 3Ps migrate into southern 3L in spring and summer, returning to 3Ps in autumn.

The isolated cod living and spawning in Gilbert Bay, southern Labrador, appear to be distinct from all other 2J3KL stocks. Other small populations in bays of southern Labrador are largely unassessed. No seal-related issues pertaining specifically to those stocks have been raised with the Seal Panel.

The complex stock structures in 2J3KL pose problems for analysis and prognosis. Again quoting DFO (2000g): "shallow coastal waters appear to be important nursery grounds of juvenile cod from both inshore of 3K and 3L and the offshore of 2J, 3K and 3L," and autumn surveys "reveal that cod occur near the coast at ages 0 and 1 and move onto the shelf as they get older." However, "it is unknown whether the recovery of the offshore is more likely through resurgence of the remnant that still remains in the offshore or from inshore fish moving offshore." Even the "significant proportion" of 3Ps fish among catches in 3L could also be a source of future offshore recruits in 2J3KL. The genetic structure of the various stocks, summarized in Lilly et al (2000, p. 10), remains controversial. Microsatellite loci have indicated considerable differentiation, even in the offshore (Beacham et al. 2000a, Ruzzante et al. 1997, 1999, 2000), but Carr and Crutcher (1998) concluded "that the mtDNA and microsatellite data confirm... a primary separation of cod on the Flemish Cap and those elsewhere in the Northwest Atlantic, but that there is otherwise little or no genetic substructuring attributable to genetically distinct stocks in this area." Of some interest in this context is a recent indication from microsatellite data (Beacham et al. 2000b) that two seasonal pulses of recruitment of 0-age cod from Bonavista Bay contained mostly local cod, but also individuals that were similar to spawning aggregations from offshore to the north. This would appear to imply the possibility of stock repopulation from non-local sources.

This uncertainty about the identity and uniqueness of local cod populations suggests that a precautionary approach be taken in the protection afforded any local stocks that could be future sources of wider repopulation.

4.11.3 Cod stock status in eastern Newfoundland

For these Divisions, the usual practice of calculating TACs from Sequential Population Analyses of the whole stock "cannot be done because of the changes in the proportion of the stock covered . . . and . . . the survey gear" (Lilly et al. 2001). There is also an "inability to reconcile reported catches and the research vessel index in the late 1980s and early 1990s" and a mixing of inshore fish in 3L with migrants from 3Ps (Lilly et al. 1999). Instead, offshore trawl surveys, inshore acoustic surveys, tagging, sentinel fisheries and responses to questionnaires all supplied information for current assessments, as summarized in DFO (2001l) and Lilly et al. (2001).

The offshore biomass monitored by autumn RV trawl surveys "declined from 1995 to 1997, increased a little in 1998, doubled from 1998 to 1999, and increased slightly in 2000" (DFO 2001i). The offshore biomass estimate of ~30 Kt, however, is still only ~ 2.5% of the 1983-1989 values (Lilly et al. 2001). Few of these fish were >50 cm and >5 y old (DFO 2001i), although there was no indication of sharp truncation of the age classes during 1995-1998 (Fig. 27 in Lilly et al. 1999). The doubling of biomass between 1998 and 1999 was mostly of ages 2 and 3 fish. Acoustic estimates of the remnant 2J population in Hawke Channel, off southern Labrador, estimated that the "biomass decreased by half from 1994-1995, decreased further in 1996, and has remained rather stable at this lower level" (DFO 2001i).

In inshore 3KL, standardized sentinel surveys produced decreasing catch rates 1998-2000 (DFO 2001i). Stock biomasses have been estimated using tagging results. "A simple migration model estimated biomass in Northern 3L and in 3K in 1998 to 2000 to have been of the order of 40,000 t. A more detailed model . . . indicated a biomass of no more than 77,000 t for 2000, of which 42,000 t was in 3K and 35,000 in Northern 3L" (DFO 2001i). The estimate of 77,000 t was revised to 64,000 t by Lilly et al. 2001, and this value is used in FRCC (2001). The inshore estimates excluded southern 3L, because some of the cod in that part of the Division are believed to come from 3Ps. The overall range of inshore and offshore estimates combined encompasses a 1998 estimate (Lilly et al. 1999) for 3K and northern 3L combined of 52 Kt, which has 95% confidence limits of 36-135 Kt: a further indication of the uncertainty of all such estimates.

The biomasses of the largest inshore wintering concentration, in Smith Sound, were assessed acoustically as about 13 Kt in 1995, 21 Kt in 1996, 23 Kt in 1997, 14 Kt in 1998, 15 Kt in 1999, 22 Kt in 2000, and 31 Kt in 2001. That local population appears to be at least maintaining its size. Small numbers have been detected by acoustic surveys elsewhere in Trinity and Bonavista bays.

Mean recruitment indices from offshore and inshore combined increased during 1996-1999 and fell somewhat in 2000, but are plagued by broad, overlapping confidence limits (Fig. 11 in DFO 2001i). Proportions of females mature at early ages increased during the early 1990s and have since stayed relatively high, but fluctuating (DFO 2001i, Fig, 8).

The cod biomass estimates can be compared with catches (bycatch, food fishery, sentinel surveys, and an index fishery) of 5 Kt in 1998, 8 Kt in 1999, and 5 Kt in 2000 (DFO 2001i; given presumably more accurately as 3.5, 8.7, and 4.66 Kt by FRCC 2001). To these must be added an unquantified take from illegal fishing, often from dockside, reported to the Panel as occurring regularly on "bay cod" stocks in SE Newfoundland. Indeed, DFO (2001i) states that "unreported catches… are rumoured to be substantial." The current conclusions (DFO 2001i) remain troubling. In the offshore even "bycatch mortality could delay or impede the recovery of the stock." Also: "Under the hypothesis of a separate inshore population, it is not clear whether the spawning stock has been sustained . . ." whereas, "under the single functional population hypothesis . . . any fishery on the remnant inshore will delay recovery of the stock."

4.11.4 Some suggested explanations, other than seals, for lack of recovery of cod

The continuing roles of fishing, and possibly unreported or illegal catches, are noted in the previous section, but it has been widely argued that such impacts, however serious in present circumstances, would be too small to completely prevent recovery in an otherwise normally functioning cod population. The issue of bycatch of small cod in shrimp trawls in offshore areas closed to cod fishing has also been raised. The Panel is satisfied that this has become a minor issue since the introduction of the "Nordmore grate" (Kulka 1997) in 1992. The total bycatch on observed vessels targeting shrimp and Greenland halibut in 2000 was estimated as <40 t (DFO 2001i), a trivial amount compared to the estimates of biomasses and directed catches of cod.

Food shortages or adverse environmental conditions can forestall maturity, and reduce fecundity and early survival rates of cod. However, mean gutted weight of cod from autumn RV surveys in 2J3KL has generally increased during the late 1990s, although dropping slightly in 2000 (DFO 2001i, Fig. 9), and the "liver index" is currently close to the long-term mean (Lilly et al. 2000, Fig. 18, 19). There is no anatomical evidence that poor condition of mature northern cod has been responsible for the current lack of recovery.

By process of elimination, a major difficulty for the recovery of northern cod stocks appears to have been poor survival. The question is: to what extent can this be attributed to predation by seals?

4.11.5 Consumption of cod by seals in eastern Newfoundland

Three main needs were evident to the 1997 workshop on interactions of harp seals with the fishery (CCFI 1997, see **4.11.1**): (1) better sampling and statistical analysis of stomach contents; (2) assessment of trends in cod consumption with diminished cod stocks; and (3) better partitioning of predation between inshore and offshore of 2J3KL. We address these needs below.

Differences among seasonal diets, both inshore and offshore, of harp seals in 2J3KL (Lawson and Stenson 1997) were incorporated by Stenson et al. (1997) in estimating their consumption of cod, yielding an increase from 46 Kt in 1981 to 88 Kt in 1994. These estimates had wide 95% confidence limits (46-140 Kt in 1994). Stansbury et al. (1998) noted that cod body weights were underestimated by the regression formula used in that analysis; this has become corrected in recent analyses (Lilly et al. 1999). Finally, another decrease in the estimated consumption of cod by harp seals resulted from the removal of some offshore samples taken near research vessels trawling for cod, which are known to be accompanied by harp seals foraging on escaped and discarded catches (see Pemberton et al. 1994).

All these adjustments have led to the current published estimate (DFO 2001i, based on Stenson and Perry 2001) of 37 Kt (95% confidence interval, 14 Kt - 62 Kt) of cod consumed by seals in 2J3KL in 1998-2000. This is considerably lower than previous published estimates for the 1990s. Lilly et al. (2001, Table 42), tabulated estimated numbers at age consumed by harp seals, indicating that some 800M individual cod were taken in 1995, of which only ~10% were >2 y old. By contrast, only 86M individuals are listed for 1998, but ~67% of these were >2 y old and ~6% were as old as age 6-7 y.

Although these recent estimates go some way to addressing the needs identified by CCFI (1997; see **4.11.1**), sampling is far from representative of the distribution of seals. For example, the current estimate (Stenson and Perry 2001) of the proportion of cod in the diet of harp seals feeding offshore between 1980 and 1998 is based on the remains of single cod recovered from each of 6 out of 552 seals. Estimates of the diet of harp seals feeding inshore are more firmly based, although estimated total consumption of cod by these animals is currently only about 50% of the total (G. Stenson, pers. comm.). The inshore series is based on very extensive samples (Stenson and Perry 2001), and does suggest that, in addition to the recent changes in age structure noted above, the amount of cod eaten has changed through time. There is a counter-intuitive increase in cod as a proportion of diet energy following the moratorium (average ~2.4% before and ~7.5% after 1993). Seal stomach contents from inshore localities are supplied by collectors who may obtain samples disproportionately in the immediate vicinity of cod concentrations. For example, two sample localities (Smith Sound and Kings Point, Bonavista Bay) where "belly feeding" has been described (see **4.11.7**) contributed prominently to the numbers of reconstructed stomach samples from inshore Div. 3L (from comparisons of tables from G. Stenson [pers. comm.] with Table 11 in Stenson and Perry [2001]). Finally, all the estimates for cod consumed by seals could be biased upwards if cod otoliths are better preserved than those of other organisms, or could be biased downwards if "belly feeding" of cod is important (see **4.11.7**).

Recently, Lawson and Hobson (2000) used stable-carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of harp seal tissues to conclude that there has been a switch in recent years from higher trophic levels (e.g., groundfishes) to lower ones (e.g., arctic cod and capelin). In contrast to the results of Stenson and Perry's (2001) analysis, this suggests that cod now form a smaller proportion of the harp seal diet than previously.

Finally, although work is underway, it is unlikely that estimates of harp seal diets based on their lipid profiles will be available in the immediate future. However, the potential of this approach is evident in a preliminary study of lipid profiles of harp seals and three prey species (Greenland halibut, capelin and arctic cod) collected in 1994-1995 (Lassner 1996). The results indicated that seals sampled inshore could be almost completely discriminated from those taken offshore; lipid profiles of the former most closely resembled that of arctic cod, whereas the offshore profiles resembled that of capelin. These results conform to those expected from the distributions of these two major prey species and their occurrences in offshore and inshore harp seal diets (Stenson and Perry 2001).

Published information on diets of hooded seals is extremely limited. Hammill and Stenson (2000, Table 8) listed Greenland halibut (118,273 t) and redfish (17,847 t) as important prey, both taken in deeper waters, but also estimated that hooded seals removed 33,633 t of cod in from 2J3KL based on inshore data collected before 1990 (Ross 1993), and on unpublished data. The estimate was also based on the assumption that hooded seal numbers had continued to increase since 1990 (the date of the last aerial survey). As noted in section 2, this assumption may not be valid. Bundy et al. (2000a. Table 2b), assumed that all of the Atlantic cod consumed by hooded seals in the period 1985 to 1987 were >35cm (i.e., 3+ y old). The basis for this assumption is not documented, but may be because the two Atlantic cod recorded by Ross (1993) were both >35 cm.

Because of this paucity of existing estimates of prey consumption by hooded seals, the Panel arranged to have available further samples processed and the entire data set re-analysed. **Table 4.3** lists the otherwise unavailable results (E. Perry and G. Stenson, DFO, pers. comm.). These estimates assume the same total consumption of prey (362,902 t) as given for 1996 by Hammill and Stenson (2000), use updated estimates of the proportion of energy supplied by each prey item (G. Stenson and E. Perry, pers. comm.), and assume that hooded seals spend 90% of their time in offshore waters when in 2J3KL (per Hammil and Stenson 2000, Appendix Table 3).

Table 4.3 Estimated annual consumptions in tonnes by hooded seals of major diet items in 2J3KL

Prey species or group	Offshore (n = 40)	Inshore (n = 317)	Total (n = 357)
Atlantic cod	98,147	635	98,782
Greenland halibut	17,800	11,613	29,413
Atlantic herring	0	1,539	1,539
Pleuronectidae	113,890	2,718	116,608
Redfish	19,499	1,629	21,12
Squid	37,952	12,005	49,957
Other fishes	38,997	3,125	42,122
Shrimp, other invertebrates	327	3,034	3,361

These are substantially different from the estimates listed by Hammill and Stenson (2000, Table 8). For example, whereas Hammill and Stenson suggested that more than three times more Greenland halibut (*Reinhardtius hippoglossoides*) as cod were consumed in 1996, the new results suggest almost the reverse. It also appears that almost three times more cod biomass was consumed by hooded seals in 1996 than estimated (above) for harp seals in 2000. The new values depend largely on offshore collections that may have little relevance for today's situation. Of the 40 offshore samples, 35 were taken between 1991 and 1994, and only one since. The amount of cod eaten by hooded seals must be rated as virtually unknown.

The available estimates of Atlantic cod consumption in 2J3KL by harp and hooded seals are much larger than the current commercial catch and, indeed, much larger than the total estimated biomass of fish >3 y old in these divisions. In inshore areas, harp seals consume an estimated 18.5 Kt of cod, half of it from a 3+ stock estimated as 40-64 Kt. Offshore, hooded seals alone are estimated to consume almost 100 Kt of cod from an estimated biomass of 30 Kt! These figures clearly indicate the uncertainties that must be associated with the individual estimates, but also indicate that harp and hooded seals are important predators on cod in these Divisions. However, the extent of this predation mortality cannot be estimated reliably at present.

4.11.6 Mulitispecies considerations for eastern Newfoundland

Even though seals are implicated as a significant source of mortality of cod in 2J3KL, it has been argued (see **Table 4.1** and section **4.6.3**) that indirect multispecies effects may mitigate the importance of this direct effect. Many of these arguments are merely hypothetical or by analogy. A more persuasive case can be made if species other than seals can be shown to have a direct, negative or positive influence on cod, and the effect of seals on the abundance of these species can be demonstrated in models of multispecies interactions. Several statements and submissions to the panel have suggested that seals may reduce the availability of particular prey species shared with cod, or may remove particular predators of cod. There is some information for 2J3KL permitting assessment of specific cases.

The link between capelin and cod has been explored, for example, in Icelandic waters, where weights of 6-y-old cod closely track capelin biomass (Jakobsson and Stefánsson 1998). Capelin are the primary prey of northern cod in 2J3KL. Capelin are also the largest single component of harp seal consumption, mostly offshore, estimated as 893 Kt (95% Confidence Interval, 682-1,100 Kt) in 2000 by Stenson and Perry (2001). Furthermore, harp seals appear actively to select capelin while being neutrally selective for cod and other fish species (Lawson et al. 1998). There has been much uncertainty in capelin biomass estimates because of disagreements among offshore acoustic and trawl-survey results and combined inshore abundance indicators. The latest stock status report on capelin (DFO 2000h), from a model combining several indices, suggests "that most year classes in the 1990's have been above average and slightly higher than year-classes in the 1980's," but "there is considerable uncertainty in the estimates." Certainly there have been marked changes in regional distribution (see section **4.5**). Carscadden et al. (2001) have analysed changes during the 1990s in distribution of capelin, which almost disappeared from southern Labrador (Div. 2J) to become centred on the northern Grand Banks area, and extended substantially to the eastern Scotian Shelf. They supported the generally held view that this change was largely driven by a southern extension of cold water. Carscadden et al. (2001) also concluded that overall predation on capelin has decreased; that is, increased consumption by harp seals has not compensated for the decline in capelin consumption as a result of the collapse of groundfish stocks. However, "there remains concern that there may not be sufficient capelin in the offshore, particularly in the north, to support good condition in cod" (DFO 2001i).

Some submissions to the Panel proposed that consumption by seals of other predators of cod would compensate for the predation by seals on cod. Two submissions speculated that predation by harp seals on squid removes a serious source of predation on cod. It is true that small cod are an important component of the diet of short-finned squid (*Illex illecebrosus*) in Newfoundland (Dawe et al. 1997). Squids in general form less than 1% of the diet of harp seals (Hammill and Stenson 2000), although much more of hooded seals (Table **4.3**) and most of these are *Gonatus* sp. (G. Stenson, pers. comm.). One submission suggested that predation on skates by seals would benefit cod. Skates are not listed as a diet item of harp seals from 2J3KL during 1982-1998 (Stenson and Perry 2001), and only one or two have been found in stomachs (G. Stenson, pers. comm.). However, the cartilaginous remains of skates are probably more rapidly digested than are the bony parts of other fish, and this could bias the estimates of skate consumption. Herring, implicated in consumption of cod eggs and elsewhere (see **4.8.2**), occur and spawn inshore in eastern Newfoundland. There is no evidence of large numbers offshore. Energetically rich, during 1995-1998 they contributed a large fraction of inshore diet energy to harp seals (23.1-34.5% in October-March, 23.1-51.2% in April-September), but have not been found in offshore diets (Stenson and Perry 2001). They were also ~7% of inshore diet energy of hooded seals (among "other fishes," **Table 4.3**). Stocks of herring, especially the 1990-1991 year classes, were assessed in 1998 as "poor to moderate" in White and Notre Dame bays, and "moderate to good" in Bonavista and Trinity bays (Wheeler et al. 1999). Given their absence in offshore diets, the suggestion that herring play a major role by preying on cod eggs and larvae, and that harp seals in 2J3KL can mitigate such predation, does not appear convincing.

Some insight into the effects of interactions between all species in the Newfoundland-Labrador Shelf ecosystem has been provided in a recent analysis by Bundy et al. (2000a), who compiled available information and indirect estimates of biomass, consumption, production, and diet of major species and species groups in 2J3KLNO during the pre-collapse period 1985-1987. These estimates produced considerable imbalances in the flows of organic matter within the overall system, at "a time of relatively constant biomass for the major commercial species." The biomasses and flows of organic matter among components were balanced using Ecopath (see **4.6.3**) and the resulting estimates of mortality rates are given in **Table 4.4**. Bundy et al. (2000a, p. 74), state that the balancing procedure did not much change the unbalanced estimates of percentage predation mortality of small cod from its main predators, large cod and harp seals. Furthermore, Savenkoff et al. (2001, their Fig. 4) produced quite similar relative predation estimates (although expressed as % predation rates in t $km^{-2}y^{-1}$) using inverse modelling. They also found that the two most important predators of small cod were harp seals and large cod, although they concluded that the former was less important than the latter. However, the results of the two approaches are expected to be similar, given that they are based on the same empirical data. It may be of interest that total predation mortality of cod on Georges Bank (Tsoui and Collie 2001), where seals are rare, is estimated to be substantially lower than that attributed to harp seals alone off eastern Newfoundland.

Table 4.4 Estimated instantaneous mortality rates of small cod from various predators in the Newfoundland-Labrador Shelf ecosystem, based on an Ecopath analysis (Bundy et al. 2000, Table 34)

Predator	Mortality rate	% of total mortality
Harp seals	0.40	26.7
Cod >35 cm	0.29	19.3
Small pelagic fishes	0.17	11.3
Greenland halibut >40 cm	0.14	9.3
Skates	0.13	8.7
Whales	0.13	8.7
Others	0.24	16.0
Total	1.50	100.0

There are important caveats about the accuracy of the original data. For example, although the harp seal data are far more extensive than those for other species (e.g., whales, for which there are no estimates from this system), there is considerable uncertainty in harp seal diets, as considered in **4.11.5**. Note also that the estimates are for the pre-collapse situation.

The system has changed radically since that time, most obviously through the great diminution of cod and other groundfish stocks and an approximate 70% increase in the harp seal population. The possible impact of these changes between 1985 and 2005 were explored by Bundy (2001) using Ecosim (see **4.6.3**). She used "scenarios" simulating changes in fishing mortality on small (<35 cm) and large (>35 cm) cod, American plaice, and small (<40 cm) and large (>40 cm) Greenland halibut, each year from 1985 to the 1994 moratoria. She also simulated a potential rate of increase in the harp seal biomass by 5% per year. Vulnerabilities to predation were modelled by three situations: (1) all prey available to predators (top-down control); (2) predation completely constrained (bottom-up control); (3) only a proportion of prey available to predators (implying the existence of prey refugia). Given the unstructured pelagic and benthic habitats of eastern Newfoundland , situation 1) was considered to be the most likely.

The model that best reproduced, at least qualitatively, observed changes in biomass of system components (10 correctly, 6 incorrectly, and 7 with unknown real trends) between 1985 and 2005 was the one based on situation (1) with 5% annual increase of the harp seal population. Among the commercial species, only the observed trends in flounders and American plaice were not reproduced. The cod population diminished sharply up to the mid-1990s as a result of fishing pressure, and had not regained its pre-collapse level by the end of the simulation in 2005. Harp seals had a greater negative impact on small cod than large. Bundy (2001) concluded that the results were consistent with the hypothesis that the collapse of the northern cod stocks was due to excess fishing, and "also support the hypothesis that the recovery of cod is currently being retarded by the increased biomass of harps seals due to predation by harp seals on cod." However, small and large cod in the model, unlike those in nature, had recovered to almost half their pre-collapse levels by the year 2000. It should be recognized that these simulations take no account of uncertainties in the estimates of energy flows between components of the system and that Ecosim is likely to be most effective at simulating the effects of small deviations from initial equilibrium conditions. In eastern Newfoundland, the system is now very different from the situation in the mid-1980s.

4.11.7 "Belly feeding" on inshore cod in eastern Newfoundland

No issue has been discussed with more fervour than the large mortalities of cod in the bays of southeast Newfoundland since the mid-1990s. The panel saw videotaped evidence from Bonavista Bay in 1999 of: extensive concentrations of cod milling slowly on the surface in some cases with an indeterminate number of seals nearby; some cod removed from or lying on the bottom with "bellies" punctured or largely ripped out; extensive bottom accumulations of dead cod in shallows, as far as the video recorder could capture in very clear water; two harp seals with large cod in their jaws. The Panel also interviewed witnesses of such mortality, and is entirely convinced that it is real. Although some damage could have been *post mortem* from gulls or crabs, there is no possibility that these have caused the massive die-offs. The phenomenon is detailed in Lilly et al. (1999, p. 14-15), to which the Panel can add little. They reported the scale of one event during January 1999 in Virgin Arm, outer Notre Dame Bay, as ~91 t of dead cod. Lilly et al. (2001, p. 25) noted that "incidents reported during the winter 2000-2001 have been less dramatic than those in previous years," but it is too soon to declare this as a trend.

Of interest is that many fish in these events have appeared moribund when first observed, and that many (most?) of those dead have been superficially undamaged ("in good condition," Lilly et al. 1999, p. 14). It appears that the main cause of death has been the entry of cod into sub-zero waters where they have succumbed to freezing damage of tissues. The question remains: were such cod forced into cold surface waters by harp seals, or did they make these fatal movements for other reasons, after which the seals were able to take advantage of easy prey? The same question was asked by Templeman (1965) in the context of reported large kills of fishes, including cod in various areas of the North Atlantic, including Newfoundland. Although some local observers stated that they had observed cod being forced by seals to move out of some bays through shallows along the shores, other causes have been mentioned. Lilly et al. (1999, p. 14) reported that "observers noted the presence of smelt in the area" of one event in Notre Dame Bay. One fisherman interviewed by the Panel thought it possible that mortalities in Bonavista Bay could have resulted from the unwise pursuit by cod of herring, known to be present in some inner bays at the time, and to attract seals. He suggested that videotapes of surface-milling cod be scrutinized for flashes of silver that might signal presence of herring in the mêlée.

Another source of information is from stomachs sampled in winter and spring close to the Smith Sound area, where there are large winter concentrations of cod and reported incidents of "belly feeding" (tables from G. Stenson, DFO, pers. comm.). Between 1992-2001, an estimated 333 cod were found in 27 of 148 (111 prey-containing) stomachs from the Smith Sound area, with no obvious trends in incidence over time. Since 1996, unassociated soft parts of fish were looked for in 111 seal stomachs containing food but not found. The measurable cod were small (average ~19 cm, ~124 g). Samples from another collector in Kings Pt., Bonavista Bay, came from near Princeton, where "belly feeding" had also been reported, and where four out of 97 stomachs since 1996 were said to contain "offal."

Finally, a short analysis presented to the Panel (Jarvis 2001, on behalf of the FFAW-CAW) suggested that "a drastic catch rate decline at the Summerford, Notre Dame Bay [sentinel-fishery] site and a significant within season decline of catch rates at the Plate Cove East, Bonavista Bay site, after similar belly-feeding incidents, may be indicative of the impact of seals." Belly-feeding incidents at Virgin Arm, near Summerford, were reported in winter 1998-1999 and at two other nearby sites in 1997-1998 and 1998-1999 respectively. There do indeed appear to have been declines in the sentinel catch rates at the Summerford site after 1998. However, an observed decline in catch rates at Plate Cove East did not occur until several months after a reported belly-feeding incident nearby in Bonnavista Bay. More serious reservations about these data are the lack of controls (other randomly chosen sentinel sites), with the further complication that any declines should also be expressed wherever the cod migrate after wintering at sites where belly feeding has occurred. Also, as noted above (**4.11.3**), whereas the status of the inshore stocks in general is unclear, there has been no evidence of decline in the overwintering cod concentration in Smith Sound, another site where such mortalities have occurred. Analysis of sentinel-fishery statistics might give insights into local population consequences of belly feeding by seals, but this would need careful attention to confounding variables and statistical design.

Some stakeholders argued that proportions of cod in harp seal diets are seriously underestimated because of belly feeding. The panel believes that the association of belly feeding with mass die-offs is largely an inshore and local phenomenon. Certainly belly feeding occurs more widely, as some stakeholders spoke of instances offshore of large fish in jaws of seals or partially eaten on ice floes, but it is unlikely that seals routinely capture large, healthy cod. Observations in Pemberton et al. (1994) are pertinent. They noted that seals fed large cod in captivity may consume them in bites, but return to finish fallen fragments. They also documented observations around trawlers of seals catching cod of mean length 49 cm that had spilled out of nets (and were presumably injured in some way), but always swallowing them head first and whole.

4.11.8 Possible impacts of seals on other stocks in eastern Newfoundland

Information on the consumption by harp seals of other groundfish species in 2J3KL during 1982-1998 can be gleaned from Table 13 in Stenson and Perry (2001). Greenland halibut contributed only about 2% of diet energy contents for seals feeding inshore, and 4% offshore. American plaice contributed about 4% of nearshore energy, and 12% of offshore energy, whereas Pleuronectidae (presumably including unidentified plaice and also non-commercial species) contributed 6% of inshore and 30% of offshore diet energy. Thus harp seals could be having an impact on these fish stocks. The recent re-estimation of hooded seal diets (**Table 4.3**), indicates that Greenland halibut is much less, and Pleuronectidae much more, important than previously estimated by Lawson et al. (1998) and Hammill and Stenson (2000). This is curious, given hooded seal's reputation as a deep-water feeder offshore, where most Greenland halibut are reputed to occur, and again suggests that the offshore samples are too small to provide reliable estimates of consumption.

Current stock status assessments of groundfish species other than cod that are, or have been, of interest to 2J3KL fisheries, are updated in DFO (2000f) and detailed in a number of NAFO SCR documents. The most important remaining groundfishery off eastern Newfoundland is for Greenland halibut. An overview of trends in distribution and abundance based on RV surveys 1978-1999 (Bowering 2000) indicated that, after a decline to an all-time low in the early 1990s, in 3K and at least in southern 2J, "from about 1995 the stock showed considerable recovery and continues to improve based upon several successive good year-classes particularly 1993-95." An SPA for the 2J3K stocks, although offered as "illustrative only because of uncertainties about stock structure . . . suggests the 2000 stock biomass for ages 5-17 is 220 000 tonnes, which is the highest observed since 1975." Another modelling exercise (extended survivor analysis; Mahe and Darby 2000) predicted that biomass would increases from about 270 Kt in 2000, peaking a few years later, then falling slowly after 2002. The Ecosim projections by Bundy (2001, Fig. 5d) are in agreement with a recovery up to 1995, although with reduced biomasses thereafter. In general, then, the biomasses of Greenland halibut appear to have responded to reduced fishing mortality, and recovery has not been affected in any obvious way by seal predation.

There is no current TAC for American plaice, the 1998 biomass of which remained at <10-15% of peak values in the early 1980s (DFO 199). The most recent assessment of offshore stocks in 3NO (NAFO 2001), where impact of seals is unknown, predicts an estimated doubling in 5 y if unfished, but no increase at 2000 (bycatch) levels of fishing. Directed fisheries have been permitted in 3LNO for the offshore yellowtail flounder *Limanda ferruginea*), which has continued to increase following a moratorium in 1995-1997. Other species in the region are subject to small, directed fisheries or bycatches. A bycatch of haddock in 2000 was mostly in inshore 3L, where its recurrence "may be a result of warming trends" (DFO 2000f).

4.11.9 Summary assessment for eastern Newfoundland

Our conclusions do not deal with the collapse of the cod stocks or with the poorly known situation in the southern Grand Banks, Div. 3NO.

Recommendations made in 1997 by an international panel for understanding interactions of harp seals and the fishery have begun to be fulfilled, but more offshore sampling, more representative inshore sampling, and better information on seasonal distributions of seals are needed.

The possible existence of a number of cod stocks in the division makes assessment complex. Local stocks may or not be genetically or otherwise capable of repopulating depleted areas, but all need to be managed for that potential.

Current abundance of cod in 2J3KL is assessed as ~30 Kt offshore and 44 Kt or 64 Kt inshore, depending on model assumptions. Even the current inshore TAC of 4.6 Kt may be sufficient to delay recovery.

There is no evidence to support the view that bycatches or poor condition of cod (from environmental influences, including food shortages) have inhibited cod stock recovery in recent years. The issue has been high mortality, in which seals have been implicated.

The current estimate of annual consumption of cod by harp seals is 37 Kt (95% confidence interval 14-62 Kt). Approximately half of the fish currently consumed in inshore waters are estimated to be >3 y old (unlike younger estimated age structures up to the mid-1990s). If these figures are even approximately correct and also apply to the fish consumed offshore, it is difficult to disagree with the most recent stock status assessment that: "There is a possibility that predation by seals is preventing the recovery of the cod stock." This view is further supported by new (although highly uncertain) estimates that the consumption of cod >3 y old by hooded seals in the offshore substantially exceeds the estimated biomass.

It is widely argued that impacts of seals can only be assessed in a multispecies context. There have been major changes in capelin distribution, but not clearly so in biomass, during the 1990s. Increased harp seal predation on capelin has apparently not replaced the large reduction of predation by cod, but offshore capelin stocks may be inadequate for much cod recovery. There is no evidence, on the other hand, that the seals may benefit cod through their consumption of cod predators. Static-flow, mass-balance models for the eastern Newfoundland Shelf in 1985-1987 concluded that seals and large cod were much the largest contributors to mortality of small cod, although the estimates are extremely imprecise. A very specific dynamic (Ecosim) model, projecting the 1987-1985 biomasses to 2005, incorporated estimates of fishing mortality on commercial species before the moratorium, a steady potential increase of harp seals numbers, and top-down control, produced conclusions that overfishing accounted for the collapse of cod stocks, and that harp seals could now be inhibiting their recovery.

The reality of local mass mortalities of inshore cod cannot be doubted, although belly feeding may only be involved in a fraction of deaths given the absence of large quantities of cod flesh in the stomachs of seals sampled in the vicinity of these incidents. The extent to which seals cause, or are simply associated with, entry of cod into fatal (freezing) conditions is not clear. Evidence that local abundance of cod have declined following such mortalities requires more careful statistical analysis.

Among other groundfish stocks, perhaps only American plaice is both highly depressed and, especially to the extent that it may included in diet "Pleuronectidae," may be subject to considerable offshore seal predation.

4.12 Possible impacts of seals on Atlantic salmon

4.12.1 Review of situation

River returns of Atlantic salmon have declined throughout Atlantic Canada. The situation is most severe in the northeastern U.S.A., where salmon have been extirpated from some rivers and declared "endangered." Salmon stocks in the Bay of Fundy area have also been greatly reduced, especially the genetically distinct, less migratory ones entering rivers around the head of the bay (extensive review by Amiro MS 2001; semi-popular account in Bay of Fundy Ecosystem Partnership 2001). COSEWIC declared the inner Bay of Fundy stocks "endangered" in 2001. In general, the condition of stocks improves somewhat with latitude as one proceeds up the Atlantic coast of Nova Scotia to Newfoundland and Labrador beyond.

Because of the widespread declines, explanations that apply to all regions have long been promoted. Fishing and predation at sea, changes in river quality, disease and marine "regime shifts" have all been implicated in the decline. It has been generally noted, however, that a widespread negative trend in adult salmon returns persists despite severely reduced commercial harvests, whereas production of smolts per adult has increased as a result of reduced competition or improved conditions in at least some freshwater systems (Amiro 1998a). Furthermore, increased at-sea mortality from reduced food supply, disease, or direct effects of temperature shifts should also be reflected in reduced size or quality of returning adults, which has not generally been the case (Cairns 2000). Indeed, Amiro (1998a) documented a positive trend between 1985 and 1997 in size and condition of returning adults at the LaHave River, NS (which he attributed to selective removal of small fish). Predation mortality at sea is widely believed to be an important cause of the failure of salmon stocks to recover.

Stakeholders have long implicated seals in the failure of salmon to recover, but only recently has the possibility received some scientific assessment. A regression analysis linking salmon decline to increased abundance of harp seals and other variables (Amiro 1998b) has been criticized on statistical grounds (ICES 1998). It is also noteworthy that the rate of decline of salmon since the 1980s has been much greater than the rate of increase of the harp seal population. The Panel can add little to the exhaustive and rigorous analysis of the potential impact of seal (and seabird) predation on salmon in Atlantic Canada by Cairns and Reddin (2000), and an assessment of what is needed to obtain and evaluate this potential by Cairns (2001). The major difficulty revealed by both these documents is the extremely low occurrence of salmon remains in even large samples collected to study seal diets in Atlantic Canada. Nevertheless, even this low incidence could reflect an important cause of at-sea salmon mortality because of the large numbers of seals involved (Cairns and Reddin 2000).

No conceivable sampling of stomachs contents or faeces could be extensive enough to give reliable estimates of numbers of salmon killed by seals at sea. The Panel is unable to assess the technical or sampling feasibility of a project suggested by P. Amiro (DFO, pers. comm.) to release large numbers of salmon smolts labelled with a rare stable isotope in an effort to trace the isotope among potential predators. The Panel is also unaware of the feasibility of detecting rare salmon predation by seals using lipid profiling. It is also doubtful that the management scenarios considered by the Panel (section 5) could have any impact on at-sea predation of salmon. However, it might be possible to both assess and mitigate localized predation by seals in estuaries and rivers where smolts and returning salmon may be most vulnerable. As noted in section **5.6**, the Panel has not attempted to recommend detailed management measures along these lines because it would he highly site specific. As noted in the Panel's sections on management (section **5**) and research recommendations (**6.6**) any implementation of local control programs should be planned and carried out to give maximal information on the extent of the predation problem and the results of such intervention.

Despite advertisements and solicitation, the Panel received only one brief from stakeholders on the issue of seal predation on salmon (Salmonid Association of Eastern Newfoundland, **Appendix 3**). In addition to calling for regulations that would "allow removal of so-called 'nuisance' seals in salmon rivers and estuaries," this brief promotes both further research on offshore diets and behaviour of harp and hooded seals as potential salmonid predators, and research on "the near shore marine food web; particularly as it relates to Atlantic salmon and sea run trout."

4.12.2 Summary of issues on Atlantic salmon

The role of seals in at-sea mortality of salmon is totally speculative. Even massive sampling of seal diets would not likely give adequate assessment of this role. Predation on smolts and returning adults in estuaries and rivers could be assessed more readily. If programs to exclude seals from selected estuaries or river mouths with important salmon runs are implemented (see section **5.6.2**) these must be conducted as carefully designed experiments (with control sites) so that the results can be properly assessed.

4.13 Impact of Seals on finfish aquaculture

4.13.1 Introduction

Much information on seals and aquaculture was supplied by Barry Hill, Aquaculture Biologist with the New Brunswick Department of Agriculture, Fisheries and Aquacuture (NB DAFA), and in comments forwarded by Nell Halse, General Manager, NB Salmon Growers Association. No other provinces, stakeholders, or individuals submitted information or concerns on the issue, possibly because salmonid aquaculture is more intensive along the NB coast of the Bay of Fundy than elsewhere in Atlantic Canada.

Sources of information include an analysis of aquaculture-pinniped interactions in Maine by a Task Force reporting to the U.S. National Marine Fisheries Service (Anon. 1996). This was "to advise the Secretary [of Commerce] on the issue and problems regarding pinnipeds interacting in a dangerous or damaging manner with the aquaculture resources in the Gulf of Maine" (Anon. 1997). The analysis was occasioned by 1995 amendments to the U.S. Marine Mammal Protection Act (MMPA) prohibiting "lethal methods," previously permissible under certain conditions. A briefer summary of the Maine situation is by Belle (1999). A less complete survey more directly pertinent to New Brunswick is by Hill (1992).

4.13.2 The seal species involved

According to Jacobs and Terhune (2000), seals along the Fundy coast of New Brunswick are almost exclusively harbour seals. Despite the fact that harbour seals in Maine have increased by about 8.7% per year since the early 1970s (Waring et al. 1997), Jacobs and Terhune (2000) found no significant differences among aerial survey counts, corrected for season, made in 1984, 1987 and 1998. The New Brunswick seals are much less abundant in winter, when most seal attacks occur, because animals apparently depart for the U.S. Northeast,. Although the panel has been informed (conversations between chair and aquaculture workers) that grey seals are involved along the Atlantic coast of Nova Scotia, we have obtained no documentation of this possibility.

4.13.3 Nature of seal impacts

In order of seriousness, these are:

1) presence of seals near cages leading to stress and attendant loss of growth and condition by the fish;
2) damage to gear by seals attacking the fish;
3) damage to or death of individuals fish seized through the nets by seals;
4) net entry and sometimes multiple killings of fish by seals; and
5) large-scale or complete escape of the fish through damaged nets (with potential conservation as well as economic impacts).

4.13.4 Costs to industry

Complete assessment of the economic costs of seal predation in aquaculture is difficult, involving as it does unreported losses, losses unclaimable through insurance, increased insurance premiums, and the costs of preventative or mitigative measures. The NMFS Task Force (Anon. 1996) gives a Maine industry estimate of "about 10% of an annual farm-gate value of about $50 million," but also notes that "this figure is not supported by any independent sources." In New Brunswick, between 1988 and 2000, $5.2 million was claimed for "predator losses" through Mitchell McConnell Insurance Co., which supplied about 50% of the coverage (B. Hill, NB DAFA, pers. comm.). It is also noted that these claims "do not include 50% of the industry, deductibles, losses below insurance action damage, or 'collateral damage' (e.g. stress induced disease and lost growth)." It is also clear that, whereas distributed losses may not be extreme, individual losses can be. Jacobs and Terhune (2000) state that, among "at least 56 insurance claims for seal attacks on cage sites in New Brunswick from 1988 to 1998 inclusive . . . the average loss per attack was CAN$110,753 . . ."

Possibly more useful than incomplete cost estimates are trends over the years (information sources as above). A graph of "percentage predator losses by year" shows more-or-less steadily increasing insurance payouts until 1996 with a sharp drop in 1997-2000. B. Hill (NB DAFA, pers. comm.) stated that: "Based on the fact that loss trends have stayed in the $1 to $1.5 million range for the last 10 years and in the same time the industry dollar value has grown from $79 million to $142 million, it would seem to indicate that the relative interactions have reduced over time."

4.13.5 Prevention techniques

Preventative measures are thoroughly reviewed by Anon. (1996) and Hill (1992). Some are impractical or unlikely to be effective, and others, such as removal of dead fish that may attract predators, are general expressions of good husbandry. Although well-designed, site-specific studies of the relative effectiveness of these different methods were called for by Anon. (1996, 1997), Belle (1999) and others, such studies apparently have not been carried out. The following techniques have been proposed or used in New Brunswick, where "industry has recognized . . . these interactions for some time and has developed a number of non-intrusive methods to limit the problems" (B. Hill, NB DAFA, pers. comm.). The non-lethal methods are considered effective when "used together to effectively control seal predation" (Nell Halse, NB Salmon Producers Association, pers. comm.). The Panel has not evaluated these methods, which are best tested, costed, implemented and paid for by the industry. Nor has it considered ways in which government financial support has been or might be involved. We have, however, commented on some techniques that may be controversial or need regulatory attention.

Siting of facility. The most important influence on incidence of seal damage may be siting of the aquaculture facility, because some growers report substantial losses and others none. However, the causes of such differences are unclear and do not appear to be related to proximity to seal haul-outs, at least in Maine (Anon. 1996, p, 37). Nor do harbour seals appear to be attracted to areas containing aquaculture facilities in New Brunswick (Jacobs and Terhune 2000). Although successful siting might thus be dismissed as a matter of "luck," more research on this subject would be useful.

Improved cages containment technology. The introduction of larger, round plastic cages, which are more resistant to environmental exposure and improve husbandry, has also reduced seal attacks, according to B. Hill (NB DAFA, pers. comm.), who rates this as "the main improvement in recent years."

Barrier nets. A variety of nets placed outside cages have been used to prevent predator access. These must be taut enough so that seals cannot gain access to fish swimming near the inner nets by pushing against them. The literature indicates that the success of this technique is much dependent on local knowledge and skills.

Seal-scaring methods. These methods are exhaustively reviewed and rated by Anon. (1996). The intrusiveness of such techniques range from merely having 24-h presence of personnel on site, to use of non-penetrating projectiles (e.g., rubber bullets). Although the NMFS Task Force recommended against the use of techniques that it rated as ineffectual, only the last was considered *a priori* unacceptable (Anon. 1996).

Underwater acoustic deterrence devices (ADDs) are widely promoted for preventing seal predation. Among many research projects listed in the Canadian Atlantic aquaculture science report for 1999/2000 (Chang and Septon 2000), the only one relating to seals was on acoustic deterrence. Earlier ADDs had short-term effects at best and were even thought to act as "dinner bells." Hill (1992) found no evidence that the incidence of "seal problems" or number of fish lost at 38 sites was related to presence or absence of ADDs. Modern ADDs, however, including those that "ramp up" sound intensity to discourage approach by seals before becoming painful, are rated by Anon (1996) as effective and as having little or no non-target impact. A recent analysis by Terhune et al. (in review) found that the highest intensities (195 dB re 1 uPa at 1 m, 2.9 msec pulses) should discomfit seals (80 dB above threshold) at 100 m, and be "clearly detectable" on a quiet day up to 7 km. However, J. Terhune (University of New Brunswick, Saint John, NB, pers. comm.) has recently found evidence of habituation, even to high-intensity ADDs, and has questioned the deterrence value of such devices at all but very close distances. Terhune et al. (in review) further concluded that: "Using high amplitude sounds to protect finfish aquaculture cages from seal predation without encountering prohibitively large capital and operating costs may not be feasible." Another view is that they "have proven effective when used in conjunction with good predator nets . . . [and when] properly located and systems stay properly charged" (comments forwarded by Nell Halse, NBSGA). Lower-intensity ADDs have been used to deter net entanglement by sea mammals, but the effects on non-target marine mammals of higher-intensity devices needs further research.

Lethal methods. In the early 1990s the salmon aquaculture industry in Charlotte Co., NB, requested issuance of permits to kill predaceous seals (J. Conway, DFO, pers. comm.). DFO instead agreed to a pilot project to help assess the numbers and impacts of the seals involved. This project, managed by the Salmon Aquaculture Association of NB, was in place for six months with a six-month extension. The operators were to log all seals shot and to retain the stomach and lower jaw for later analysis. In the event, 31 seals were logged as killed, no samples were collected, and the project was terminated. At present, Canadian Marine Mammal Regulations do not contain anything specific on "nuisance seals" or "predator control," although the Panel understands that an amendment to the Regulations is being developed (G. Melano, DFO, pers. comm. June 6, 2001). A licensed fisherman may be issued a regular fishing license governing sealing. However, there is no open season for harbour seals. Furthermore, the license can only be issued to fishers, which excludes aquaculture operators. Thus, under current regulations, no harbour seals can be killed in the act of damaging aquaculture gear or invading salmon pens.

The U.S. Task Force, responding to the 1995 revision of the MMPA, had difficulty achieving unanimity on the killing of seals that have actually entered fish pens. The final recommendations to Congress (Anon. 1997) merely state that "In the rare event that a seal is [in] a net-pen . . . an intolerable situation that seems to have no legal means of resolution, the NMFS believes that lethal methods may be necessary." In the absence of regulations, Anon. (1996) refers to anecdotal reports of seals being killed illegally. The same has undoubtedly occurred in Atlantic Canada (G. Conway, DFO, pers. comm.).

4.13.6 Summary of issues on seals and aquaculture

Seal damage in New Brunswick, and probably elsewhere in Atlantic Canada, has apparently become broadly tolerable with increasingly sophisticated prevention and mitigation through insurance. Non-lethal methods of prevention and mitigation of seal damage appear to be effective, although the non-insurable impact of seal predation on individual growers may be devastating. Full consultation with the aquaculture industry is needed before any changes of the Marine Mammal Regulations to permit the killing of nuisance seals in narrow circumstances are implemented.

4.14 General conclusions and recommendations on impacts of seals on fisheries

Conclusions:

In all regions, estimates of the consumption by seals of different fish species, especially those such as cod that are a relatively small component of the diet, are highly uncertain. There are additional sources of uncertainty, such as in the age-specific metabolic requirements of seals, which have yet to be accounted for in these estimates. Although there is still only limited information on the seasonal and spatial distribution of seals, there is sufficient information to indicate that current and historical sampling of seal stomachs for diet analysis is highly unrepresentative. For example, most of the harp and hooded seals in the Northwest Atlantic feed offshore in Divisions 2J3KL, but only a small proportion of samples have come from this area. Even in inshore areas, sampling locations are determined more by the distribution of sealing communities than the distribution of seals. Finally, samples collected in the 1980s and early 1990s, which make up the bulk of the available material, may have little relevance in today's much changed conditions. Estimation of diets from fatty acid profiles of seal blubber could reduce sampling bias, but the methodology has yet to be fully reviewed and published.

Despite these caveats, the available estimates indicate that seals consume large amounts of fish throughout Atlantic Canada, but there is much less evidence that this predation is having a major impact on most commercial fish stocks. However, in Divisions 4RS3Pn, and 2J3KL the estimated consumptions of cod by seals are large in relation to estimated cod biomasses, and indicate that seal predation is a substantial component of the high mortality apparently being experienced by these stocks. In 4VsW, where the estimated consumption of cod by grey seals is also high, the situation is less clear because new estimates of grey seal consumption, based on fatty acid profiles, are scheduled to be made available later this year. Preliminary indications are that these will result in a reduction in the estimated consumption of cod by seals in these Divisions.

Conclusions about the effects of seals on various fish stocks and fisheries within each NAFO Division or Subdivision in Atlantic Canada have been detailed in this report. The belief, expressed by some stakeholders, that reduction of seal numbers will rapidly restore fisheries is overly optimistic: even in “normal” mortality régimes, the expectation is for very slow recovery. Ongoing research to place seal predation in an ecosystem context is unlikely, at least in the near future, to give definitive answers on the longer-term consequences of managing seal populations for the benefit of fisheries. Single-species population models incorporating estimated mortality from seal predation or simplified, "minimum realistic" multi-species models may, however, be useful in predicting the short-term effects of reduced mortality caused by seals on the size of depleted fish stocks. In Divisions 2J3KL and 4RS3Pn the estimated consumptions of cod, and some other commercial species, are so large that a large reduction in seal predation could reasonably be expected to have a substantial effect on the size of these stocks. However, any calculation of the benefits that might result from such a reduction must take account of the uncertainties involved in the estimates of seal consumption, and of the effects of changes in seal numbers on other stakeholder communities. In section 5 we use a number of different management scenarios to indicate how these calculations could be carried out.

A letter to the Panel Chair from Panel Member David Vardy, dated 30 July 2001 (Appendix 5), includes the following statement. "In the case of Atlantic cod, to which the Panel has directed much of its attention, the evidence has led Panel Member David Vardy to the conclusion that seal predation is making such a large contribution to the high level of mortality as to delay or possibly prevent recovery. The low level to which the spawning biomass of Northern cod has been reduced, with virtually no recovery since the moratorium of 1992, combined with the loss of larger spawners from the stock, are factors that make this stock particularly vulnerable to seal predation. Seal predation poses a serious threat to the recovery of Northern cod and other important cod stocks in Atlantic Canada and to the rebuilding of these stocks to their historical levels. He has requested that this dissenting statement be inserted in the Final Report of the Panel of Eminent Persons to the Minister of Fisheries and Oceans for Canada and that this letter be appended to the Report."

Recommendations:

The amount of funding currently allocated to seal diet research is inadequate, and the lack of multi-year funding for such research hampers the design and execution of statistically sound programs. Support for this work could come from fisheries research "A-base" budgets, in recognition of the fact that predation mortality is now a key component of fisheries management.

5. MANAGEMENT OBJECTIVES

5.1 Introduction

In this section, we explicitly address one of the Panel's objectives (the development of a strategic harvesting plan for seal populations) and two of the key deliverables (advice on management strategies to attain an optimum population size, and advice on the most appropriate strategic directions for management of seal populations). Some of these deliverables are predicated on the Panel's ability to identify "the optimum size of seal populations in terms of their interactions with other components of the ecosystem." Any change in the abundance of a particular seal species will have implications for the stock size of many other species within the ecosystem, and for the potential value of those stocks that are commercially exploited. For example, a reduction in harp seal numbers on the Newfoundland-Labrador Shelf may lead to an increase in the abundance of Atlantic cod and an eventual increase in the TAC for this species. But the change in seal numbers would also lead to an immediate reduction in the TAC for seals. In the longer term, any increase in Atlantic cod could lead to a reduction in the abundance of shrimp and crab (see, for example, Bundy 2001), and therefore in the TAC for these stocks.

If utility values can be attached to the different outcomes that may result from a change in seal numbers, then techniques such as Bayesian decision analysis (Harwood 2000) can, in principle, be used to identify optimum sizes for seal populations. However, the Panel's terms of reference do not provide any guidance on these values. For example, in order to calculate an optimum population size for harp seals we would need to know how the potential costs of a change in the seal TAC should be compared with the potential benefits of a reduction in the time taken for the northern cod stock to recover to a level at which full-scale commercial exploitation could begin again. The Panel was therefore unable to identify a single optimum size for any of the seal populations in Atlantic Canada, and therefore cannot advise on "management strategies to attain such an optimum population size."

Instead, we have considered a number of different management scenarios. In the status-quo (**5.2.1**) and market-forces (**5.2.2**) scenarios the primary objective of management is to maintain or improve the income of the sealing industry. In the consumption-stabilization (**5.2.4**) and seal-reduction (**5.2.5**) scenarios the primary objective is to regulate or reduce removals of commercially important fish. In all cases, we have tried to apply sound conservation and resource-management principles, including the precautionary principle. There are winners and losers under each of the scenarios, and the uncertainty associated with some of the benefits is often very much greater than that associated with some of the costs. Any decision about which stakeholder group should have the greatest chance of benefiting from seal management and which should lose out must be a political and not a scientific one.

The Panel considered the likely effects of the management scenarios on three stakeholder groups:

- sealers
- commercial fisheries targeted at demersal species (both through their effect on removals

of cod, Greenland halibut and American plaice by seals, and through their impact on removals of species like capelin that are consumed by those fish species), and

- DFO itself.

We did not consider how the seal tourism industry might be affected under each scenario because demand for this industry is unlikely to be directly related to the size of seal populations or the TACs that are set for seals. Provided that seal numbers do not drop to such a low level that breeding aggregations are hard to find, demand should be independent of seal numbers.

We focussed on the management of harp seals, because this is the species on which most data are available and about which the greatest concerns were expressed to the Panel. However, we have also considered how the same approaches might be applied to hooded seals and grey seals. Although the Panel was asked to provide advice "on the most appropriate strategic directions for management of seal populations . . . in particular for the next five years," it will be more than five years before the effects of any of the scenarios we have outlined will be evident and we have therefore not limited our considerations to this time horizon.

Broad levels of uncertainty have, where possible, been assigned to the potential costs and benefits that could accrue to stakeholders under the different scenarios. Thus an outcome that we believe has a high probability of occurring has a "low" level of uncertainty, whereas those that are based on highly variable data (for example, those used to estimate seal consumption of fish) have "high" levels of uncertainty. The various sources of uncertainty are discussed below.

5.1.1 Uncertainty in estimates of consumption of fish by seals

For a number of scenarios we have calculated the likely change in consumption of different fish species that will occur in NAFO Divisions 2J3KL, because this is where the best information is available on seal diets and on the associated uncertainties. We have also calculated confidence intervals for these estimates using formulae developed by DFO scientists. **Appendix 4** provides a detailed description of the basis for these calculations and full tabulations of the estimates and their coefficients of variation. These calculations take account of uncertainty in the estimation of diet, uncertainty about the proportion of time seals spend in Canadian Atlantic waters, and uncertainty about the proportion of time spent within 25 km of the shore. When a scenarios predicts that the seal population will increase, we have also taken account of uncertainty in the estimates of seal population size, because these affect the predicted changes in fish consumption. For scenarios that involve a deliberate reduction in the size of the seal herd, we have not included uncertainty in the estimation of population size since we assume that the number of seals killed (including those shot but not recovered) will be known relatively precisely.

It should be recognized that these calculations do not take account of all sources of uncertainty in the estimation of fish consumption. As noted in section 4, no account is made for uncertainty in the estimation of the daily energy requirement of seals of different ages. In addition, there are uncertainties about how pregnancy rates will change over time, and the implications of this for seal numbers. It is tempting to interpret the decline in seal pregnancy rates that have been observed over the last 30 years as a density-dependent response to increasing seal numbers.

However, there have been dramatic changes in the abundance of major seal prey species, particularly capelin and arctic cod, over this period and, as described in **2.4.1**, the observed changes in pregnancy rates may not be directly related to seal numbers *per se*. As a result, there is no obvious way of accounting for uncertainty about future changes in pregnancy rates.

Another important concern about our estimates of changes in prey consumption is that they are based on the assumption that the composition of the harp seal's diet will remain constant over time. This assumes that the diet of the average seal is unaffected by changes in the abundance of prey species, harp seal numbers or environmental conditions, and that the distribution of harp seals between inshore and offshore waters will also remain constant.

5.1.2 Uncertainties about the Greenland hunt

The Greenland hunt for harp seals has increased from less than 10,000 per year in the early 1970s to nearly 90,000 in 1999. Reported catches in the first 9 months of 2000 were 65,157, implying an annual catch of around 87,000. This may be one reason why the 2001 Seal Management Plan suggests that the Greenland hunt has stabilized at around 80,000 animals. Other authors (e.g., Stenson and Healey 1999, Lavigne and Johnston 2001) have assumed that the hunt will continue to increase at the rate observed during the 1990s, resulting in a predicted catch of 130,000 by 2005. The Greenland hunt is subsidized, and therefore not driven by market forces. As a result, future trends in this hunt are unpredictable but if a recent proposal to develop a seal processing plant in Greenland is realized, this could cause a further increase in catches.

Struck-and-lost rates in the Greenland hunt are believed to be high because seals are often shot in the water. To account for this, it is assumed that two seals are killed for every one landed. In addition, most of the animals taken are adults and juveniles, whereas the Canadian commercial hunt is mostly of young of the year. As a result of these two factors, changes in the scale of the Greenland hunt can have a substantial effect on the size of the population and on the proportion of the calculated Replacement Yield from the population that can be allocated as a TAC in the Gulf and Front. The scale and nature of the Greenland hunt for both harp and hooded seals is a major source of unquantifiable uncertainty in all of the predictions about seal numbers and fish consumption that are made under the following scenarios.

5.1.3 Implications for groundfish stocks and TACs

We have not attempted to calculate the potential effects of the calculated changes in consumption of Atlantic cod, Greenland halibut, and American plaice on the size of the commercially exploitable stocks of these species, nor have we speculated on the consequences of these effects for the TACs that might eventually be set for these stocks. This is because of the extreme sensitivity of such calculations to the assumptions that are made about the way in which mortality rates on these stocks might change over time, as described in detail by Mohn and Bowen (1996). In addition, calculations of the effects of seal consumption on mortality rates for fish stocks require information on the numbers of fish of different ages consumed by the seals. Although such estimates have been made (e.g., Stansbury et al. 1998, Lilly et al. 2001), there are undocumented, but undoubtedly large, uncertainties involved in deriving them from estimates of the total biomass of each fish species consumed by seals. Finally, it is not clear how the effects of changes in the biomass of the different prey species of harp seals caused by a change in seal abundance will propagate through the ecosystem. For example, the predicted changes in the consumption of capelin and flatfish following an increase in the harp seal TAC by 150,000 for five years (see **Figure 5.2**) are 40 times those predicted for consumption of Atlantic cod (170 Kt compared with 4 Kt). Winters and Miller (2001) suggest that these changes will all have favourable consequences for Atlantic cod. However, a detailed quantitative analysis using a wide range of assumptions about the scale and nature of the interactions between the different component species of the ecosystem on the Newfoundland-Labrador Shelf is required before their conclusion can be considered as anything more than speculation.

5.1.4 Control rules and Limit Reference Points

Fisheries scientists have been endeavouring for a number of years to develop management procedures that take account of uncertainty. Canadian scientists contributing to the work of NAFO and ICES have been in the forefront of this work, but seal management in Canada has not taken advantage of these developments.

These procedures are based on a set of control rules that determine the size of the TAC and the way in which it is implemented, and a set of Reference Points that are used to monitor the effectiveness of the management process. In particular, a Limit Reference Point (or Points) is identified. The management procedure must ensure that the probability of the population falling below any of the Limit Reference Points is less than an agreed level. Usually an appropriate set of control rules and Reference Points is identified by testing the performance of a suite of potential management procedures on a computer model of the target population.

The current implementation of the US Marine Mammal Protection Act is an example of this approach (see **5.4**). In this case, the Limit Reference Point is defined as the population level at which maximum net productivity occurs (equivalent to the level for maximum sustainable yield in some fisheries models) and the acceptable risk of the population falling below this reference point has been set at 5%. This is a relatively conservative strategy.

Caddy (1998) reviewed the Limit Reference Points that have been used for a range of fish stocks, and particularly those currently used by ICES and NAFO. Almost all are based on parameters that are conventionally estimated from the age structure of commercial or research catches of the target species (e.g., total mortality, fishing mortality or recruitment – see Figure 10 in Caddy [1998]). None of these are likely to be particularly useful for harp seals because of the complex nature of the hunt and the difficulty of obtaining reliable age structure data. However, biomass or, more likely, total population size could form the basis for a Limit Reference Point. As we discuss below, it may be possible to obtain samples that are representative of the population's age structure from the hunt in Nunavut, because this hunt is relatively unselective.

The ICES/NAFO Working Group on Harp and Hooded Seals (ICES 2000) was asked to identify B_{lim}, B_{msy} and other biomass-based reference points for Northeast Atlantic harp seals. They concluded that B_{msy} (the biomass level at which maximum net productivity is achieved) was an inappropriate reference level for marine mammals. They suggested that B_{lim} (a critical biomass level below which recruitment is reduced) might be an appropriate reference point, but were unable to calculate it for the Northeast Atlantic harp seal population.

Winters and Miller (2001) have calculated a value of B_{lim} for the Northwest Atlantic harp seal population. They suggested it should be a population of 800,000 animals one year and older (equivalent to a total population of approximately 1 million). This was based on Lett et al.'s (1981) prediction that, at this population level, age of maturity was as low and pregnancy rate as high as was biologically feasible. There is no potential for the population to increase its per capita productivity if numbers fall below this level. If Lett et al. (1981) were correct in their conclusion, this would indeed be an estimate of B_{lim}. However, more than 20 years of additional data on Northwest Atlantic harp seals have accumulated since Lett et al. performed their analysis. As we describe in **2.4.1**, when an internally consistent subset of the current time series of data on reproduction and population size was analysed, the evidence for a purely density-dependent relationship between pregnancy rate and harp seal population size was far less convincing than implied by Figure 22 in Winters and Miller (2001). That figure combines estimates, some of which are of dubious validity, of pregnancy rate and population size made using a variety of different methods. A more pragmatic approach (also considered by Winters and Miller) is to use 1.7-1.8 million animals, the lowest estimate of total population size from Healey and Stenson (2000), as an estimate of B_{lim}. We know that the harp seal population was capable of increasing from these levels, which occurred during the early 1970s, under a regime of low catches.

It seems likely that the harp seal population will continue to be monitored by aerial surveys of pup production, and that the results of these surveys will be used as the basis for a Limit Reference Point. Although pup production is a reliable index of population size if pregnancy rates remain constant, it will always lag behind changes in total population size. This lag is most marked when exploitation is directed primarily at pups, as in the commercial hunt for harp seals. Because most harp seals are not fully recruited to the breeding population until they are 6- to 7-years old, it will take at least this time before any overexploitation of pups will be reflected in a reduced pup production. The implications of this delay must be accounted for in the management procedure.

Other variables may be more responsive to overexploitation than pup production, and these could be used with pup production to make up a 'basket' of Limit Reference Points, as advocated by Caddy (1998). A representative sample of the population's age structure should show the effects of overexploitation or an unexpectedly high mortality of particular year-classes before it is reflected in reduced pup production. For example, the 1986-1988 year-classes of the Northeast Atlantic harp seal population are virtually absent from the age structure of Norwegian samples of moulting harp seals taken since 1990 (Kjellqwist et al. 1995) because large numbers of pups born in these years died after entanglement in fishing nets along the Norwegian coast and because of reduced abundance of capelin in the Barents Sea.

However, there is now considerable evidence that management procedures that use observational information directly are more effective and more likely to meet management objectives than those that rely on estimates of parameters derived from these observations (e.g., Cooke 1995, Geremont et al. 1999, Punt and Smith 1999, Milner-Gulland et al. 2001). Therefore the Limit Reference Point should be based on change in the age structure itself and not on changes in some demographic parameter (such as a year-class-specific survival rate) derived from that structure.

Although there are considerable logistic problems involved in obtaining a representative sample of the population's age structure, it is possible that one could be obtained from the Nunavut hunt. The Panel recommends that the possibility of obtaining a regular scientific sample from this hunt should be investigated.

All of these suggestions imply that any new management strategy that is adopted for the Northwest Atlantic harp seal population should be firmly based on a risk analysis approach, as advocated by the ICES/NAFO working group on harp and hooded seals (ICES 2000) and by Winters and Miller (2001). This would bring the management of harp seals into line with the approach adopted for many of the fish stocks on which NAFO and ICES provide management advice. The Panel did not attempt to develop a management procedure along these lines because of the limited time and computer programming expertise at its disposal. However, it recommends that DFO urgently commission a study to develop a generic set of control rules and Reference Points that could be applied to any of the management scenarios described below. Experience gained in the development of the Revised Management Procedure of the International Whaling Commission (Cooke 1995), the PBR concept which forms part of the US Marine Mammal Protection Act (see Wade 1998), and in other related studies (e.g., Milner-Gulland et al. 2001) could be used to develop such a management procedure relatively quickly, and possibly before the start of the 2002 sealing season.

5.2 Management scenarios for the harp seal

5.2.1 Status quo

Under this scenario the harp seal herd is managed in the same way as it was until the 2001 season. That is, the TAC is set at the calculated Replacement Yield, making allowance for anticipated catches in Nunavut and Greenland, bycatch in the lumpfish fishery and US gillnet fisheries, and animals struck and lost in different hunts.

The objective of this management strategy is not entirely clear to the Panel. The 2001 Seal Management Plan (DFO 2001a) simply states that the objective is that the hunt is "managed on a long-term, sustainable basis." However, this is rather different from the precautionary approach used in setting TACs for fish stocks in Atlantic Canada, where one of the management objectives is a low probability that a stock will decline. In the case of the harp seal TAC, there is a rather high probability (approximately 50%) that the seal population will decline if the TAC is taken in full each year.

In practice, the TAC has not been taken in full every year. The actual harvest is driven primarily by market forces (particularly the price for pelts), ice conditions and, historically, by the nature and extent of subsidies. As a result, with the exception of 1998, the actual catch has been substantially below the TAC. Of course, the actual catch should never exceed a properly enforced TAC, so the expectation is that average annual removals over an interval between surveys will be less than the Replacement Yield. As a result the probability that the total population will decline between surveys is less than 50%. We would therefore expect a gradual increase in seal numbers under this scenario, although it could take a decade before any increase will be reflected in a significant increase in observed pup production. However, this prediction is affected by uncertainties associated with future changes in pregnancy rates, the effect of occasional mass mortalities of pups caused by poor ice conditions, and uncertainties about future trends in the Greenland hunt and the market for seal products.

The anticipated costs and benefits to stakeholders are shown in **Table 5.1**. It is not possible to calculate the probable changes in consumption of cod, Greenland halibut, and American plaice under this scenario because of the uncertainties about the factors likely to affect seal population size. However, **Figure 5.1** shows the change in consumption of Atlantic cod, Greenland halibut, American plaice and capelin that would result from an annual increase of 3% in seal numbers. The actual rate of increase in seal numbers under this scenario is likely to be less than 3%

Table 5.1 Predicted costs and benefits to stakeholders under a "status-quo" scenario

Stakeholder	**Costs**	**Uncertainty**	**Benefits**	**Uncertainty**
Sealers	None		Relatively stable TACs over period between surveys.	Low
			Likely increase in TAC after 10 years	Moderate
Demersal fisheries	Consumption of cod, Greenland halibut and American plaice likely to increase.	Moderate	None	
	Consumption of capelin likely to increase.	Low		
	Mortality on cod, Greenland halibut and American plaice likely to increase.	High		
DFO	None, beyond present costs.		None	

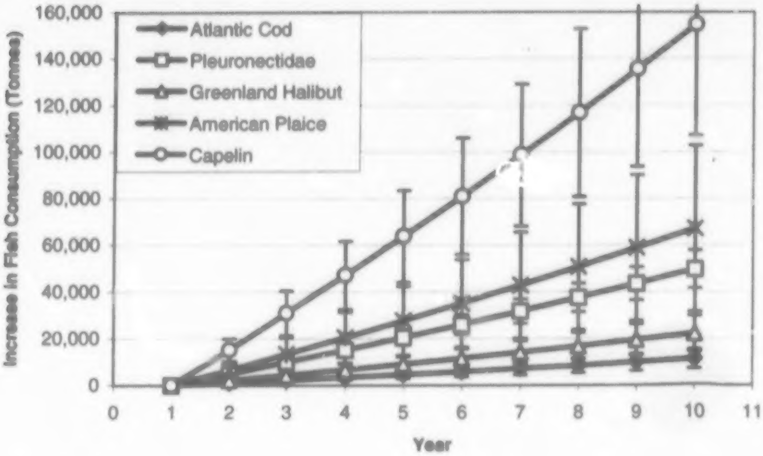

Figure 5.1 Calculated changes in consumption of Atlantic cod, capelin, Greenland halibut, American plaice and other flatfish (Pleuronectidae) in 2J3KL following a 3% per annum increase in harp seal numbers. This is the expected rate of increase if the seal TACs are set on the basis of the PBR criterion of the US Marine Mammal Protection Act. All values are shown ± 1 standard deviation.

5.2.2 Harvest regulated by market forces

Under this scenario, market forces rather than an annual TAC are allowed to determine the size of the catch in any particular year, subject to the constraint that the population should not fall below some Limit Reference Point or Points. The aim would be to allow professional sealers to maximize their net income, while ensuring that this income was sustainable. This approach would facilitate the orderly growth of the sealing industry. Its effects on demersal fish stocks will depend on the discount rate applied by sealers to future revenues and market demand for seal products.

It would be prudent to issue only professional sealing licences under this scenario, and to limit the total number of such licences that are issued. This would prevent the development of over-capacity in the sealing industry. We do not believe that very large numbers of seals will be taken immediately under this scenario, because this would result in a cycle of "boom and bust." Large catches that seriously deplete the population are likely to lead to reduced pelt prices, because of over-supply, and would be followed by a period when the seal hunt will need to be completely closed to allow the population to recover. Even if a large market for seal products (such as seal oil capsules) that is less volatile than that for pelts can be found, the risk of periodic complete closure (and potential total loss of a carefully established market) should ensure that the seal population normally remains well above the Limit Reference Point.

If suitable Limit Reference Points and control rules can be developed for this scenario, we do not anticipate that there will be an immediate increase in average catch levels. This is because, over the observed range of harp seal population sizes, Replacement Yield has increased steadily with population size (**Figure 2.2**). Thus any dramatic increase in current catches would have a substantial

Table 5.2 Predicted costs and benefits to stakeholders under a market forces scenario with a low discount rate

Stakeholder	Costs	Uncertainty	Benefits	Uncertainty
Sealers	Need to determine acceptable levels of catch each year		Able to adjust size, age and sex structure of catch so that supply of seal products best matches market demand	
			Should result in increased annual per capita income	Moderate
Demersal fisheries	Consumption of cod, Greenland halibut, and American plaice likely to increase	Moderate	None	
	Consumption of capelin likely to increase	Low		
	Mortality of cod, Greenland halibut and American plaice likely to increase	High		
DFO	Possible increased monitoring costs		Reduced research and administration costs associated with setting and enforcing TACs	
	Cost of developing appropriate risk-based management			

negative effect on future catches. The sealing industry might even be willing to trade off a temporary reduction in the annual take against higher catches in the future, but their willingness to do so will depend on the discount rate that is applied to the value of these future catches. Likely costs and benefits to stakeholders under this scenario with a low discount rate are shown in **Table 5.2**. Given the current volatility of the market, we anticipate that the discount rate will be high and a large-scale voluntary reduction in the annual take is unlikely. Indeed, if a very high discount is applied, it may be in the sealers' interest to harvest as many seals as the market will take, in which case high catches may be taken and seal numbers will decline towards the Limit Reference Point. Likely costs and benefits under this scenario are shown in **Table 5.3**. For low discount rates, the costs and benefits to stakeholders other than sealers will be similar to those experienced under the status quo (**5.2.1**) and consumption stabilization (**5.2.3**) scenarios. However, benefits to sealers will be greater because they will be able, for example, to take more seals than would otherwise be allowed under those scenarios in years when pelt prices are high.

Table 5.3 Predicted costs and benefits to stakeholders under a market forces scenario with a high discount rate

Stakeholder	**Costs**	**Uncertainty**	**Benefits**	**Uncertainty**
Sealers	Need to determine acceptable levels of catch each year Temporary closure of fishery (i.e., zero TAC) as seal population approaches Limit Reference Point	Low	Able to adjust size, age and sex structure of catch so that supply of seal products best matches market demand and anticipated future benefits Increased aggregate per capita income	Low
Demersal fisheries			Consumption of cod, Greenland halibut, and American plaice likely to decrease. Consumption of capelin likely to decrease. Mortality on cod, turbot, and American plaice likely to decrease	High Moderate High
DFO	Possible increased monitoring costs Cost of developing appropriate risk-based management		Reduced research and administration costs associated with setting and enforcing TACs	

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5.2.3 Manage under the PBR criterion of the US Marine Mammal Protection Act

As noted in **5.1**, implementation of the US Marine Mammal Protection Act involves a management procedure based on control rules and a Limit Reference Point. Although this management procedure is actually used to regulate incidental catches of marine mammals in US commercial fisheries, a number of authors (Johnston et al. 2000, ICES 2000, Winters and Miller 2001) have noted that it could be used to set TACs for commercial seal hunts. The chosen Limit Reference Point is the population size at which net productivity is maximized. However, it is difficult to estimate a value for this Reference Point for most marine mammal populations. Although the aim of the Act is to eliminate all human-induced mortality of marine mammals, except for Aboriginal subsistence hunts, priorities for reducing mortality are set by calculating the number of animals that can be removed from a population subject to the constraint that the risk of the population falling below the Limit Reference Point is less than 5%. This number is known as the Potential Biological Removal (PBR). Extensive computer simulations, described in Wade (1998), were used to develop the following formula, which is used to calculate the PBR for a population:

$$\mathrm{PBR} = N_{MIN} \bullet R_{MAX} \bullet F_R/2$$

where N_{MIN} is a minimum population estimate (usually the lower 20th percentile of distribution of the population estimate), R_{MAX} is the maximum rate of increase of the population (often set at a default value of 0.12 for seals), and F_R is a correction factor that depends on whether or not the population is considered to be below the Limit Reference Point.

Johnston et al. (2000), Lavigne and Johnston (2001) and the US National Marine Fisheries Service (USNMFS 2001) have calculated PBR values for the Northwest Atlantic harp seal population. Values obtained under the assumption that the population is above the Limit Reference Point (i.e., with $F_R = 1.0$) and using the most recent population estimates have varied from 201,000 (Lavigne and Johnston, 2001) to 312,000 (USNMFS 2001). All these estimates are substantially less than current levels of removal from the population (Gulf and Front TAC, plus estimated Nunavut and Greenland catches). However, the PBR formula assumes that animals are taken at random from the population. Current catches are actually made up of approximately 70% young of the year and 30% animals more than one year old (Healey and Stenson 2000).

An approximation to the PBR for a hunt with the current age structure can be calculated relatively easily. Because the PBR is a risk-averse approach, a population managed under this approach should, on average, increase over time. In fact, with the PBR values calculated by Lavigne and Johnston (2001) and USNMFS (2001) the population is expected to increase at approximately 3% per year, if the pregnancy rates observed in the 1990s continue to apply. We need to calculate a PBR for removals that have an age structure similar to the current hunt. This age structure will, of course, vary depending on the relative magnitudes of the Greenland and Canadian hunts. If the Greenland catch remains at its current level of around 90,000 the Gulf and Front TAC would need to be reduced to around 135,000 animals for it to have the same effect on the population as the PBR values calculated by the above authors. However, if the Greenland hunt could be reduced to 50,000 animals, a Gulf and Front TAC of approximately 250,000 would have the same effect on the population. Because these TACs would probably allow the seal population to increase, the PBR value, and hence the TAC, will probably increase after approximately 10 years. The increases in fish consumption that are calculated to result from a 3% annual increase in seal numbers are shown in **Figure 5.1**. Annual consumption of Atlantic cod is calculated to have increased by 4.7 Kt after 5 years. Approximately half of these fish (i.e., 2.3 Kt) would be more than 3 years old, using the proportion of cod in these age classes consumed by harp seals feeding inshore estimated by Lilly et al. (1999, their Table 39). However, it should be recognized that the coefficient of variation for the calculated consumption is large (37%) when account is taken of the uncertainties described in **5.1.1.**

Table 5.4 Predicted costs and benefits of managing the Northwest Atlantic harp seal herd according to the PBR formula of the US Marine Mammal Protection Act

Stakeholder	Costs	Uncertainty	Benefits	Uncertainty
Sealers	Reduced TAC for 10-15 years	None	Stable TACs between surveys Likely increase in TAC after 10-15 years	None Low
Demersal fisheries	Increased consumption of demersal fish and capelin	Medium	None	
DFO	Need to negotiate agreement with Greenland on setting joint TACs		Setting of TACs simplified (calculation only needed in year of survey)	None

5.2.4 Harvest regulated to stabilize fish consumption by seals

In this scenario, the objective is to stabilize the harp seal population at its current level in order to ensure that consumption of fish by seals does not increase. The most obvious way to implement this is to set the TAC at the Replacement Yield and ensure that any shortfall in actual catch is made up by killing additional animals after the commercial hunt closes. One way in which this could be achieved is by paying Canadian sealers to take adult seals on the moulting patches after the end of the sealing season. These seals would not be landed, but disposed of at sea. The actual number of animals to be taken in this way would have to be carefully calculated each year, because the age structure of removals would be rather different from that of the commercial hunt, and this will affect the Replacement Yield.

The effectiveness of this form of management will depend on what is considered an acceptable risk of achieving the stated objectives. Because of uncertainties about the current size of the harp seal population, there is a 50% probability that the true Replacement Yield is actually higher than the calculated value. As a result, there is a 50% probability that seal numbers, and therefore fish consumption, will actually increase from year to year. If this risk of increased fish consumption was considered unacceptable, the TAC could be set above the best estimate for Replacement Yield. For example, it could be set at the upper 95% percentile of the distribution of calculated Replacement Yields shown in Figure 6 of Healey and Stenson (2000). If this strategy is implemented, there is only a 5% probability that consumption of fish will increase (subject to all of the assumptions described in **5.1**), but there is a high probability that removals of seals will exceed the Replacement Yield and that the harp seal population will decline. However, it will be many years before this decline is detected in seal surveys. Once a decline is detected, the TAC for Canadian sealers would have to be cut substantially.

The predicted costs and benefits to stakeholders under scenarios in which a 50% risk of increased consumption and a 5% risk of increased consumption are considered acceptable are summarized in **Tables 5.5** and **5.6**. It may be thought that DFO could gain some scientific benefit, and reduce its costs, by collecting diet, age structure and pregnancy rate samples from any animals taken on the moulting patches. However, these benefits are likely to be small because moulting animals do not feed, and therefore their stomachs will be empty, and it is impossible to determine whether moulting animals are pregnant with any reliability. In addition, the age stucture of the moulting groups is known to vary substantially from year to year. Some information on diet may, however, be deduced from the fatty acid profiles of these animals.

Table 5.5 Predicted costs and benefits to stakeholders from a scenario aimed at ensuring that there is a 50% risk that fish consumption by seals will increase.

Stakeholder	**Costs**	**Uncert-ainty**	**Benefits**	**Uncert-ainty**
Sealers	TAC may be reduced after 10-15 years.	~50%	Stable TAC over the period between surveys	Moderate (because of uncertainty about Greenland catch)
Demersal fisheries	Increased consumption of demersal fish and capelin	~50%	Decreased consumption of demersal fish and capelin	~50%
DFO	Cost of killing animals on the moulting patches	None	Improved diet information from moulting samples	Low

Table 5.6 Predicted costs and benefits to stakeholders from a scenario aimed at ensuring that there is a 5% risk that fish consumption by seals will increase

Stakeholder	**Costs**	**Uncert-ainty**	**Benefits**	**Uncert-ainty**
Sealers	TAC reduced after 10-15 years	Low	Stable TAC over the period between surveys	Moderate (because of uncertainty about Greenland catch)
Demersal fisheries	None		Decreased consumption of demersal fish and capelin	Low
DFO	Cost of killing animals on the moulting patches	None	Improved diet information from moulting samples	Low

5.2.5 Manage to reduce the seal population by a predetermined amount

The objective under this scenario is to reduce the quantity of fish consumed by seals, in the expectation that this will reduce overall mortality and speed up the recovery of those groundfish stocks, like northern cod, that are seriously depleted. As Winters and Miller (2001) point out, a scenario of this kind is effectively a form of experimental management. However, it is an experiment without a control and with no replicates. It will therefore be impossible to evaluate whether or not it has been a success, except in terms of the actual reduction in seal numbers. Rather, it should be viewed as a speculative, high-risk venture whose potential future benefits are considered by government to outweigh the costs.

We consider three ways of achieving a reduction in seal numbers: an increase in the commercial TAC for a limited period (see, for example, Stenson and Healey 1999) with a supplementary cull of young animals if this TAC is not taken in full; a series of culls of adult females carried out on the moulting patches (as recommended by Winters and Miller (2001)); and the sterilization of a large number of adult females using immunocontraception. **Figures 5.2** and **5.3** show the changes in fish consumption that are calculated to occur if the TAC is increased by 150,000 for five years (we have assumed that all of these additional animals will be young of the year), if 75,000 or 150,000 adult females are culled annually for the same period, and if 150,000 adult females are sterilized each year. These figures also show the calculated effect of taking an additional 750,000 pups in one year. If this regime could be implemented, it would effectively remove an entire year's pup production. This is unlikely to be practicable, but we have included it to illustrate the effect of removing a total of 750,000 pups in less than five years.

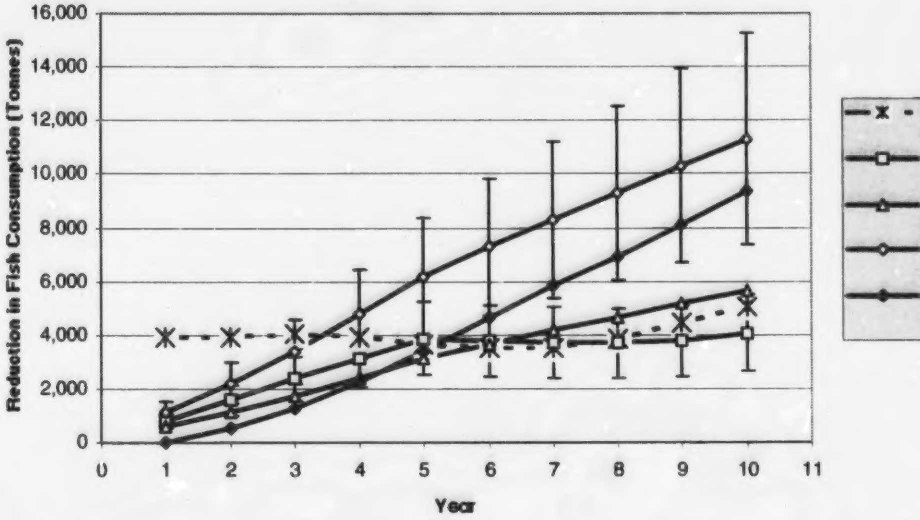

Figure 5.2 Calculated effects of a number of different methods of population reduction on the quantity of Atlantic cod consumed by harp seals in 2J3KL. Values for a reduction from an annual cull of 150,000 adult females and from increasing the annual TAC by 150,000 seals (assumed all pups) are shown ± 1 standard deviation.

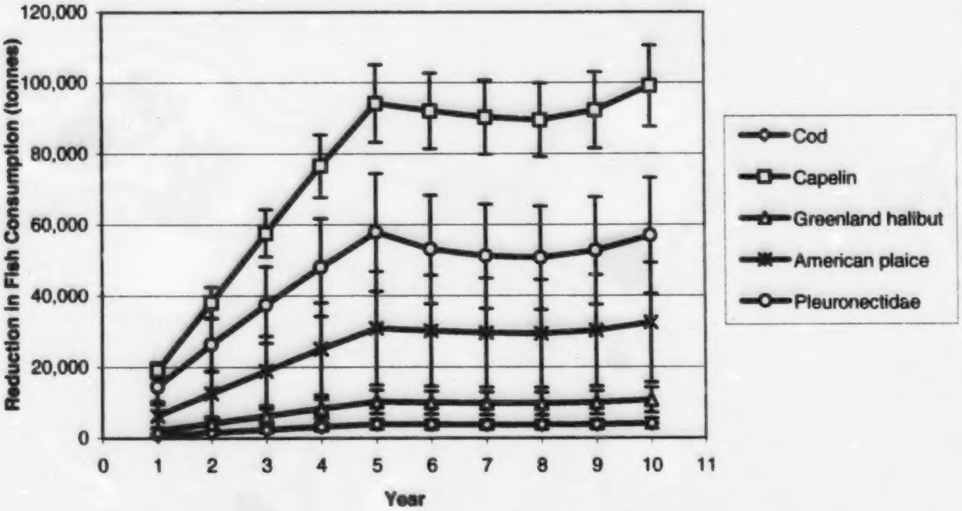

Figure 5.3 Calculated effects of increasing the seal TAC by 150,000 animals (assumed to be all pups) for 5 years on the consumption of Atlantic cod, capelin, Greenland halibut, American plaice and other flatfish (Pleuronectidae) by harp seals in 2J3KL. Values are shown ± 1 standard deviation.

Many of the sealers whom the Panel met indicated that they would be reluctant to take more seals than the current TAC because they feared this could swamp the market and reduce pelt prices. It is therefore likely that an increased TAC would not be taken in full each year, and that a substantial cull would be required to make up numbers.A sterilization programme may undermine the market for seal oil capsules and some other seal products because of consumer fears.

Four of the five regimes (increased TACs, cull of 75,000 females and sterilization of 150,000 females) have a very similar effect after five years, by which time an additional 375,000-750,000 seals will have been killed. After this time, the annual consumption of Atlantic cod is calculated to have been reduced by 3.1-3.9 Kt. Using the proportion of 3 year-old cod in the diet of inshore feeding harp seals between 1987 and 1995 estimated by Lilly et al. (1999, their Table 39), this would represent approximately 1.5-1.9 Kt of commercially-exploitable fish. For comparison, setting a zero TAC for Atlantic cod in 2J3KL in 2000 would have resulted in a reduction of around 4 Kt in the removals of commercially exploitable fish. However, a high level of uncertainty is associated with the calculation of the reduction in the quantity of Atlantic cod consumed by seals following a cull: the coefficient of variation on this estimate is 35%. A cull of 150,000 females per year would, of course, result in a higher calculated reduction in Atlantic cod consumption of 6.2 Kt, also with a coefficient of variation of 35%. We have not tried to account for the fact that some of the 0, 1 and 2 year-old cod not consumed by seals as a result of the culls will recruit to the commercial fishery in later years. Such a calculation requires an estimate of the mortality rate for juvenile cod in 2J3KL, but none is available at the moment. Winters and Miller (2001) did attempt this calculation, but they had to use an estimate of juvenile mortality for North Sea cod that may not be applicable to 2J3KL.

The above calculations are based on the assumption that the harp seal Replacement Yield will be recalculated each year to take account of the number of seals already culled, and that this will be used to calculate a "normal" seal TAC. The number of seals to be culled will then be added to this. If, instead, this "normal" TAC is maintained at the current level of 275,000, the number of seals taken in this part of the hunt may well exceed the Replacement Yield. As a result, the harp seal population, and hence its consumption of fish, will decrease by a greater amount than our calculations suggest.

Extrapolation of the calculated reduction in removals to provide an estimate of the potential benefit to groundfish fisheries requires a large number of assumptions. These include assumptions about how the other predators of young and adult Atlantic cod, which include the surviving harp seals, will respond to changes in cod abundance, and how the effects of altered predation on other prey species will propagate through the ecosystem. These are discussed at length in **4.** Winters and Miller (2001) by-passed some of these assumptions by calculating the possible effect of removing the entire Northwest Atlantic harp seal at some time in the 1980s. They conclude that this would have resulted in an increased yield to the cod fishery of 150 Kt. However, their calculation does not take account of any of the uncertainties described in **4.6.3**, **4.11.6** and **5.4.1**, it makes a number of very specific assumptions about juvenile mortality of cod, and is only valid if all harp seals are instantaneously removed from the Northwest Atlantic.

Additional potential benefits under this scenario include a reduced risk of heavy seal predation on overwintering aggregations of cod in inshore waters, and an increased probability that northern cod stocks will recover to fully expoitable levels (suggested as a spawning stock biomass of 200– 400 Kt by Lilly et al. 2001) within a particular time horizon. There are large uncertainties associated with the second of these benefits. Recovery of northern cod will only occur when a number of large year classes have appeared and have been recruited to the spawning stock. Seal numbers are unlikely to have much effect on the probability that the first of these events will occur, but they may affect the probability that when such an event does occur those year classes will recruit to the breeding population. That is, a very strong year class will be able to escape from any predator pit, but a moderate year class may not. However, most of the culls described above will only reduce the quantity of cod consumed by harp seals by around 10%. Much larger culls may be required if the objective is to "rescue" cod from such a pit.

The risks to inshore cod aggregations will depend on the behaviour of the surviving seals. If they spend more time in inshore waters than the satellite tagged seals that form the basis for the current calculations of fish consumption, then the risks may not decline at all. If they spend less time in inshore waters, the risks will be reduced further.

The costs under this scenario are primarily borne by the sealing industry and DFO. Although seal landings will initially rise, the effect of this on income will depend on how the market responds to the increased supply of seal pelts. Past experience suggests that prices will probably fall. Once the target reduction in seal numbers has been achieved, seal TACs will have to be substantially reduced. The actual size of these TACs will depend on the size of the Greenland catch at that time. Stenson and Healey's (1999) calculations suggest that with a Greenland catch of 90,000 animals the TAC for the Gulf and Front would be around 13,000 animals if the seal population was reduced to 3 million, and around 95,000 if it was reduced to 4 million. If the Greenland catch is higher than this, it may not be possible to set any TAC.

Table 5.7 Predicted costs and benefits to stakeholders under a seal reduction scenario

Stakeholder	Costs	Uncertainty	Benefits	Uncertainty
Sealers	TAC will decline sharply after 5-10 years.	Low	Increased catches for 5 years Increased net income	Low Moderate (depends on market demand)
Demersal fisheries	None		Consumption of cod, Greenland halibut, and American plaice likely to decrease Consumption of capelin likely to decrease Mortality on cod, turbot, and American plaice likely to decrease	Moderate coeff.of variation (33-52%) Low coeff. of variation (12%) High
DFO	Cost of required culls Possible increased monitoring costs Cost of developing appropriate risk-based management approach		None	

5.2.6 Seal exclusion zones and other local actions

As noted in 5.2.5, any reduction in the risk to inshore aggregations of cod that results from a large-scale reduction in seal numbers will depend on how much time the surviving seals chose to spend in inshore waters. Given this, and the large uncertainities about the benefits to the recovery of northern cod associated with that scenario, we have considered an alternative scenario based on an increased kill of harp seals in inshore waters. Data from satellite transmitters (Stenson and Sjare 1998, Stenson and Perry 2001) and a comparison of the fatty acid profiles of seals sampled inshore with those of animals sampled offshore (Lassner 1996) suggest that individual harp seals do not move routinely between inshore and offshore areas. Rather, they appear to spend extended periods in one area or the other. If this is the case, then a cull of seals in inshore waters could have a more predictable effect on predation on inshore cod than would a large increase in the seal TAC.

The Panel has not developed precise scenarios for this approach and has not, therefore carried out any cost-benefit analysis. Different implementations could range from authorizing the seal hunters currently employed by DFO to collect diet samples in inshore waters to kill any seal observed in the vicinity of cod aggregations, to the conduct of a cull through a net fishery for harp seals in inshore waters along the east coast of Newfoundland and the north shore of the Gulf. The latter approach is probably the only way to kill large numbers of seals in inshore waters, because they spend very little time on the ice in this area. However, it should be remembered that the net fishery was originally phased out on the recommendation of the Royal Commission on Seals and Sealing (Malouf 1986) "in view of the suffering [by seals] involved."

The FRCC has recommended the establishment of seal exclusion zones in inshore areas where there are large overwintering aggregations of Atlantic cod (FRCC 2001), an approach similar to the first of the above implementations. The Panel considers that such an approach is only practicable in fjord-like environments, like Smith Sound in eastern Newfoundland, where the presence of seals within a localized area can readily be identified. The benefits cannot be quantified with the information that is currently available. However, a trial operation using DFO's trained seal collectors would allow the feasibility of seal exclusion zones to be evaluated, and would provide additional information on the diet of these animals (particularly if fatty acid profiles from their blubber can be obtained). Any such a trial should be considered as a scientific experiment, with appropriate replication and monitoring of control areas from which seals are not excluded.

5.3 Management scenarios for hooded seal

The lack of a reliable estimate of the current size of the Northwest Atlantic hooded seal population, or of natural mortality rates in this population, make it impossible to provide any specific management advice. As noted in section **2.6.2**, the Replacement Yield in 1990 for this population was probably in the range of 12,000 to 57,000. Average annual removals, taking account of animals struck and lost, have averaged around 23,000 since 1993 and may therefore have exceeded the Replacement Yield.

A new analysis of the stomach contents of hooded seals commissioned by the Panel has indicated that Atlantic cod may make up a higher percentage (24% rather than 10%) of their diet in offshore waters than previously estimated. Applying this revised percentage to the figures in Table 8 of Hammill and Stenson (2000), suggests that hooded seals could be consuming three times as much Atlantic cod as harp seals in 2J3KL (**4.11.5**). If this estimate is correct, hooded seals are a much more important predator on mature cod in the offshore waters of the Newfoundland-Labrador shelf than harp seals. Thus, a cull of hooded seals could have a greater effect on the recovery of cod stocks in those management areas than an equivalent cull of harp seals. However, it should be recognized that this estimate is based on a very small sample size (only 40 stomachs from offshore waters where hooded seals are estimaed to spend 90% of their time) and on the assumption that the hooded seal population has increased by nearly 5% per annum since the last survey in 1990.

Until a new estimate of pup production is obtained it is not possible to evaluate the costs and benefits of management scenarios along the lines of those described for harp seals in **5.2.** However, it should be recognized that the uncertainties associated with potential outcomes will be substantially greater than for harp seals. This is because there are no reliable estimates of adult mortality for hooded seals. It will therefore be necessary to assume a very wide range of feasible values for this parameter.

The Canadian Sealers Association requested that the Panel consider the effects of changing the current definition of a "blueback" hooded seal in the sealing regulations (i.e., as a young seal that has not yet moulted its first coat). The prohibition on the taking of whitecoat harp seals and blueback hooded seals was introduced in response to the European Union's ban on the importation of products from "baby" seals (i.e., seals that were still in the care of their mothers). Hooded seal pups are weaned before they are 10 days, but their first moult does not occur until they are 15-16 months old. Therefore, a complete ban on the taking of bluebacks provides a much greater level of protection for young hooded seals than the ban on the taking of whitecoat harp seals. The Panel believes that an appropriate opening date for the hooded seal hunt can be chosen that will ensure that no "baby" hooded seals are taken, without resorting to a complete ban on the hunting of bluebacks. These would provide a large benefit to the sealing industry, because blueback pelts are particularly valuable.

It should be recognized that such a change in the regulations would almost certainly result in the Canadian hooded seal TAC (currently set at 10,000) being taken in full each year. As noted in **2.6.2**, it is not clear that this TAC does ensure that the total take from this population is less than the Replacement Yield, once account is taken of the full effect of the Greenland hunt. Simply changing the regulations could therefore result in overexploitation of this population, particularly if aerial surveys are carried out infrequently (as has been the case to date). The Panel therefore recommends that no change in sealing regulations is implemented until a new aerial survey of hooded seal pup production on the Front has been completed. The results of this survey should be used to provide a new estimate of Replacement Yield, and the TAC for the Gulf and Front hunt should take account of all other sources of mortality in the same way as does the TAC for harp seals.

5.4 Management scenarios for grey seal

In this section we consider how some of the management scenarios outlined in **5.2** might be applied to grey seals. There are considerable uncertainties associated with current estimates of the diet of grey seals, particularly for seals feeding on the Scotian Shelf. These uncertainties are magnified when estimates of seal consumption are used as inputs to models of the dynamics of Atlantic cod stocks. As noted in section **4** there is no consensus on the role of predation by grey seals in the recovery of any of the Atlantic cod stocks in Canadian waters. This situation may be resolved when estimates of grey seal diet derived from fatty acid profiles are made available later this year. However, with the information currently available, the Panel was unable to make any prediction of the likely effects of changes in grey seal numbers on the recovery of Atlantic cod stocks, or of the potential benefits to demersal fisheries from a managed reduction in grey seal numbers.

5.4.1 Status quo

There is currently no TAC for grey seals and only a small number of seals are taken commercially each year. Catches may increase if a market for grey seal products can be found, but any increase is likely to be small in the immediate future. The Panel therefore anticipates that grey seal numbers will continue to increase under this scenario, although not necessarily at the same rate as observed for the last 20 years. Total consumption of all fish is also, therefore, likely to rise.

5.4.2 Harvest regulated to maintain consumption of fish by seals

As noted above, the current demand for grey seal products is insufficient to support a commercial hunt that will take the full Replacement Yield from the Northwest Atlantic population. In order to stabilize seal numbers, it will therefore be necessary for DFO to take action itself. Grey seals are difficult to shoot outside the pupping season, and management action will therefore have to be carried out on the breeding colonies. Because the numbers of grey seals pupping in the Gulf appear to have stabilized, and may be decreasing, culling of seals in this area is unlikely to have any great effect on the population. Thus, the only site where management action is likely to be effective is on Sable Island. Experimental trials have indicated that shooting of adults on Sable Island results in a mass exodus of animals from the colony (D. Bowen, DFO, pers. comm.) and this is unlikely to be a practicable option. It therefore seems that the only way in which this scenario can be enacted is to use immunocontraception techniques on pups and adult animals, or to open Sable Island to commercial hunting of grey seal pups. R. Mohn (DFO, pers. comm.) has developed a spreadsheet that can be used to calculate how many animals must be treated in this way each year to achieve a particular target population within a specified time horizon. It should be recognized that immunocontraception has a smaller short-term effect on population size, and therefore on fish consumption (see **Figure 5.2**), than killing the same number of adult animals.

5.4.3 Harvest regulated by market forces

Because the current harvest is much smaller than the Replacement Yield, the implications of this scenario are identical to those described in **5.4.1**.

5.4.4 Manage to reduce the seal population by a predetermined amount

As noted in the introduction to this section, there is no scientific consensus on the effects that grey seals are having on the recovery of cod stocks. In these circumstances it is not possible to predict the consequences of any specified reduction in the size of the grey seal population with any confidence. All of the caveats associated with the likely benefits from a reduction in harp seal numbers that are noted in **5.2.5** apply with even greater force to grey seals. However, one of the costs associated with a reduction in harp seals numbers (an eventual reduction in the seal TAC) will not apply to this scenario. The practicalities involved in implementing this scenario are the same as those associated with the scenario described in **5.4.2**, although the required scale of operations will be substantially greater.

5.4.5 Local management action

The FRCC (F. Woodman, Chairman of the FRCC, *in litt*, see **Appendix 3**) has suggested that a trial grey seal exclusion zone should be established in Sydney Bight, Cape Breton Island, presumably because there is a large grey seal haul-out in this area. However, the topography of this area is very different from, for example, Smith Sound in Newfoundland. The Panel doubts that it would be possible to maintain a seal exclusion zone here, because there is likely to be a continuous turnover of the individual seals using the area. If an attempt is made to establish a seal exclusion zone at this site, it should be treated in the same experimental way as exclusion zones for harp seals in Newfoundland (**5.1.6**).

6. Directions for Future Research

The Panel's inability to provide firm recommendations for the management of seals in Atlantic Canada is, to a large extent, a consequence of a lack of information in certain key areas. In particular, there are large uncertainties associated with published estimates of the total quantities of different fish species consumed by seals, as a consequence of imprecise information on seal diet and, for some species, on seal numbers. Many of the representations the Panel received from stakeholders focussed on the perceived impact of seals upon the recovery of groundfish stocks. This led the Panel to examine the available information on the status of these stocks and the high levels of mortality reported from them in considerable detail. For this reason, the Panel is recommending research that goes beyond seal research *per se* and deals with matters that affect the basic biology of groundfish stocks.

The Panel does not provide a detailed research agenda. Rather, we point out what we believe are the most appropriate directions for future research and highlight the need for increased funding to clarify the uncertainties that cloud policy decisions.

6.1 Seal diets

The consumption of groundfish and other fish species by harp, hooded and grey seals is a key issue. The uncertainties associated with the estimates of seal diet have been detailed in section 4. The amount of funding currently allocated to seal diet analysis is woefully inadequate, and the lack of an ongoing multi-year plan to fund such research has hampered the design and execution of a statistically sound sampling program. It should be recognized that this is fundamental to an understanding of groundfish stock recovery. Resources allocated to groundfish research need to be made available to improve the estimation of seal consumption by conventional means, such as the analysis of stomach contents, and newer techniques, such as fatty acid profiles.

As noted in section 4, the distribution of stomach sampling does not reflect the known distribution of seals. This is most obvious in the contrast between samples collected from inshore and offshore waters around Newfoundland. Sample sizes from inshore areas are an order of magnitude larger than those from the offshore where seals are known to spend most of their time. Similar problems exist in inshore areas, where sampling seems to reflect the distribution of seal collectors (and to some extent cod concentrations) rather than the distribution of seals. These sampling problems have undoubtedly contributed the major uncertainties associated with the currently available estimates of seal diets. The Panel recommends a detailed statistical analysis of the available data to determine the contribution of temporal, spatial, and age-related variability to the overall variance in the estimates of diet composition. This analysis should then be used to design an optimal sampling program that will substantially reduce that variance. This design should not be constrained by the cost of obtaining adequate samples from the offshore.

Additional satellite tracking of harp and hooded seals is urgently required to ensure that the design of a diet sampling program adequately reflects the distribution of seals, and existing information on the distribution of satellite-tagged grey seals needs to be published as soon as possible. At present, information on harp seal distribution is only available for two years in the mid-1990s and information on hooded seals is based on a tiny sample size. Given the estimates from very few samples that large quantities of larger cod may be consumed offshore by hooded seals, there is an urgent need for more work on this species. For both species, sample sizes need to be sufficiently large that they can provide reliable estimates of the distribution of both young and old animals, and to identify any associations between the distributions of seals and aggregations of sensitive groundfish stocks. Existing data from grey seal studies should provide a guide to the appropriate sample sizes for harp and hooded seals.

In addition to the sampling of seal stomachs and faeces, it is important to pursue research using other techniques identified in section 4. In particular, the work already conducted on the use of fatty acid profiles to estimate the diet of grey seals needs to be written up as soon as possible. Once it has been peer-reviewed, that technique should be applied to existing harp and hooded seal samples, and sampling of blubber from these species should be extended.

6.2 Population Estimates

Published information on the size and distribution of grey, hooded and harbour seals in Atlantic Canada leaves much to be desired. One reason for the Panel's inability to offer detailed advice on the management of stocks of grey and hooded seals is because of the absence of up-to-date survey information. The last complete survey for hooded seals was in 1990/91, and virtually no hard data on hooded seals have been gathered since that time. The last survey of Sable Island, where most Canadian grey seals breed, was in 1997 and the results of earlier surveys have not yet been published. In particular, a full aerial survey of hooded seal breeding aggregations in the Gulf and on the Front is urgently needed. If possible, this survey should be extended to include the breeding aggregation in the Davis Strait.

The appropriate frequency for future surveys of harp, hooded, and grey seals will depend on how precisely the current population size needs to be known. The level of precision required will in turn depend on how these populations are being managed. There is an urgent need to develop a generic approach to the management of seal stocks in Atlantic Canada that is compatible with that used for the management of groundfish stocks in NAFO and ICES. This will involve the identification of specific management objectives and risk levels, suitable control rules, and Limit Reference Points. A seal-monitoring program that is independent of the sealing industry will be an essential component of that management framework. This will require guaranteed long-term funding if it is to be effective. This monitoring will need to be conducted in as cost-effective way as possible, and the Panel recommends further investigation of the use of digital technology for the collection and analysis of aerial photographs of seal breeding aggregations.

The estimation of total population size from surveys of pup production, and the extrapolation of future changes in the size of seal populations, require information on key demographic parameters, particularly adult survival rates and age-specific pregnancy rates. There are no reliable estimates of adult mortality of hooded seals, and this generates large uncertainties in the estimates of total numbers and Replacement Yields. There is therefore an urgent need for more work on the estimation of mortality rates for this species. In the harp seal population, there have been clear changes in age-specific pregnancy rates over time that could have important consequences for future changes in population size and Replacement Yields. However, it is not clear whether these changes have been a consequence of changes in seal numbers *per se* or changes in, for example, prey availability. The Panel therefore recommends a reanalysis of the available pregnancy data on harp seals, perhaps along the lines of the analysis described by Boyd (2000), to determine the relationship between pregnancy and a range of biological factors. Such a relationship could be incorporated into the procedure used to estimate total population size from pup censuses (Healey and Stenson 2000) to provide more reliable projections of possible changes in the size of the Northwest Atlantic harp seal population. As noted in section **5**, changes in population age structure may be more appropriate as Limit Reference Points than pup production when large numbers of harp and hooded seal pups are being harvested. The Panel therefore recommends that the age structure of the hunt for these seals in Nunavut should be investigated to determine if annual scientific samples from this area could be used as the basis for Limit Reference Points.

Some of the sampling problems described in the previous paragraph can probably also be addressed if suitable samples can be obtained from the hunts for harp and hooded seals in Greenland. In addition, the scale of the Greenland hunts has important implications for the TACs that can be set for these species in the Gulf and on the Front. The Panel therefore suggests that Canada and Greenland should develop a joint research and management program for harp seals and hooded seals.

6.3 Groundfish research

As noted in **6.1**, the most pressing questions posed to the Panel by stakeholders relate to the recovery of depressed groundfish stocks, particularly Atlantic cod. The role of seal predation in the recovery of groundfish stocks cannot be addressed adequately without a more complete understanding of other factors influencing cod mortality and limiting recovery. It is in this context that the Panel recommends that not only seal diet research but the full range of research on marine mammals, including seals, should be viewed as an important component of groundfish research. Funding for seal research should be given the same priority as other core components of groundfish research. Furthermore, the questions relating to groundfish mortality are of such profound importance that DFO should accelerate its program of research on the causes of high mortality of groundfish stocks. This will require detailed monitoring of the size, survival and growth of individual cod year-classes before they are recruited to the commercial fishery.

6.4 Capelin

It is clear that capelin is an important food component for harp and grey seals and for many groundfish species, particularly Atlantic cod, off Newfoundland and in the Gulf of St. Lawrence. Published information suggests that the total consumption of capelin by all predators has probably declined since the late 1980s, and that the cod in neither region is showing current evidence of food shortage. However, this does not necessarily mean that sufficient capelin will be available to groundfish in the future if and when depleted ground stocks begin to recover, especially since there have been recent changes in the distribution of capelin. There appears to be no scientific consensus on the current size and status of capelin stocks, but it is apparent that the level of resources committed to the surveying of capelin resources has diminished in recent years, with fewer beach surveys and the curtailment of the dedicated capelin trawl survey. The reinstatement of a full stock assessment program is of vital importance if the interactions among the different predators of capelin are to be properly understood.

6.5 Technical and professional resources

The conduct of research into such issues as seal diets and population dynamics is a highly demanding and increasingly mathematical exercise. The availability of people with the highly specialized skills required has been, and still is, a limiting factor. The research programs we have recommended will only be implemented effectively if seal biologist in each of the three regions can rely on access to researchers with these skills on a regular basis.

6.6 Seal Exclusion Zones

Although the Panel has suggested (**5.2.6**, **5.4.5**) that properly designed trials of seal exclusion zones in narrow circumstances might give useful insights, it is not convinced that lethal removal of (possibly only a few) seals will afford significant protection of overwintering aggregations of northern cod or for Atlantic salmon returning to spawn. Additional protection might be provided by acoustic and other devices that deter seals from coming into these sensitive zones. The Panel recommends that a contractor be engaged to review existing technologies that could be used for this purpose.

6.7 Statistical and economic research

The Panel has had difficulty in accessing consistent and accurate data on the economic value of the sealing industry to sealers as well as the product value of seals. The Panel has also had difficulty in determining the level of financial support provided to the sealing industry by government. Governments should be more transparent about the level of support they provide to the sealing industry, whether directly in the form of subsidies to the industry, or indirectly through research into seals and their management, and by the provision of monitoring and icebreakers during the seal hunt.

6.8 General conclusion

The terms of reference given to the Panel at the outset of its work contain the following statement: "The panel will base its work primarily on review of available reports, information, and surveys since there is abundant material available." Although large amounts of information on particular aspects of seal and groundfish biology were available to the Panel, information on other key aspects was inadequate to allow the Panel to recommend clear policy directions. It is clear, however, that seals are inextricably linked to many of the major issues that confound the future of fisheries in

Atlantic Canada. If the inadequacies in information on seal and groundfish biology are to be addressed, appropriate research has to be given a higher priority, and provided with adequate and consistent levels of funding.

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APPENDIX 1

Eminent Panel on Seal Management
Terms of Reference and Panel Members

Terms of Reference

Introduction

Management of seal populations has elicited a wide range of public opinion in Canada for many years. Recently the question of the potential impacts of seal predation on commercial fish stocks has become of public interest, while the « traditional » issues related to appropriate harvest levels and harvesting young animals continue to stir public debate.

Management of seal populations was considered in 1999 by the Fisheries Resource Conservation Council and the Standing Committee on Fisheries and Oceans, who provided recommendations on management strategies including suggestions that seal populations should be reduced to foster recovery of fish populations. (Appendix 1)

In response to a recommendation from the Standing Committee on Fisheries and Oceans, the Minister of Fisheries and Oceans will establish a panel of eminent persons to provide advice on the best strategies for management of seal populations in Atlantic Canada, including a balanced and objective review of scientific information on seal populations and predator-prey relationships and how this information can contribute to development of management strategies.

Objectives

To evaluate the current state of scientific knowledge and to provide advice on long-term strategies for management of seal populations in Atlantic Canada;
To develop a strategic harvesting plan for seal populations over a 5-year period.

Deliverables

The panel will provide a report by October 15, 2000, summarising its conclusions and recommendations. A progress report will be provided by July 15, 2000. The final report will include the following :

- a brief description of the ecological context, marine waters and ecosystems of the northwest Atlantic in which seal populations live;

- a brief description of the life history and ecological characteristics of the major Atlantic seal species

- an assessment of the available scientific information on dynamics of seal populations and the ecosystems of which they are part, for example (but not restricted to) :

- methods for estimating seal population abundance;
- methods for estimating total mortality, in particular hunting mortality including unreported losses, and information on the impact of the hunt on seal populations;
- knowledge of diet of seals and of the impact of seal predation on fish stocks;
- the optimum size of seal populations in terms of their interactions with other components of the ecosystem.

- if an optimum size of the seal population can be identified, advice on management strategies to attain such an optimum population size.

- advice on directions for improving scientific knowledge of dynamics of seal populations and the ecosystems of which they are part, to ensure that the scientific basis for seal management is sound.

- advice on whether and to what extent seal exclusion zones or experimental culls would provide protection to vulnerable local populations of commercial fishes;

- an assessment of all sources of harvest mortality on Atlantic seal stocks including but not restricted to harvests inside and outside Canada and mortality of animals struck and lost;

- advice on the most appropriate strategic directions for management of seal populations in the context of the above considerations and analyses and in particular for the next five years.

In preparing its report, the Panel may wish to consider:

- measures currently in force in Atlantic Canada to conserve and protect seal stocks, and to manage the harvesting of seals, including the adequacy of such measures, and necessary changes;

- the concerns of provinces, stakeholders and individuals and groups with a direct, indirect or declared interest in sealing in Atlantic Canada;

- positions taken by interest groups in Canada and abroad on sealing policies and activities in Atlantic Canada and the extent to which such positions can contribute to seal population management strategies;

- the implications of killing seals for non-consumptive purposes (for example protecting prey species), and the desirability of developing management strategies based on non-consumptive harvesting.

The report will be addressed to the Minister of Fisheries and Oceans. Documents developed by the panel (working papers, meeting minutes, contract reports etc) will become the property of the Department of Fisheries and Oceans.

Mode of operation

The panel will base its work primarily on review of available reports, information, and surveys since there is abundant material available. The mandate of the panel is not to conduct a broad consultation on seal harvesting in general, but the panel may wish to consult parties with information or an interest in this issue for information directly related to their objectives. The panel will be able to contract expertise to summarise information and fill in information gaps (for example to provide a bibliography of essential scientific publications; to provide a summary of available information on positions taken relative to sealing in Canada; etc).

The panel will consider recommendations of the Standing Committee on Fisheries and Oceans, of the Fisheries Resource Conservation Council, of provinces, stakeholders and individuals on management strategies for Atlantic seal populations.

The panel will consider experience and information from Canada and from other countries in preparing its report.

The Chair of the Panel will coordinate work of the Panel members such that the work is completed and report provided as required.

Recommendation of Standing Committee on Fisheries and Oceans.

Recommendation 1.

The Committee recommends the formation of a panel of eminent persons, similar to the Independent Review Panel on Northern Cod (the « Harris Report »). The purpose of the panel would be to evaluate the current state of scientific knowledge and to provide advice on a long-term strategy for the management of the seal populations.

The panel must develop a five-year strategic reduction and utilization plan and report on items, including but not necessarily limited to the following :

- scientific methodologies for estimating seal populations;
- scientific methodologies for estimating the total magnitude of the hunt including unreported losses and best estimates of the long-term impact of the hunt on seal populations;
- the current state of knowledge about the diet of seals and the impact of seal consumption on cod and other commercial fish stocks and to provide advice on directions for improving the state of scientific knowledge in this regard; and
- the optimum size of the harp seal population in terms of its interaction with the ecosystem in general and with commercial fish stocks in particular and guidance with respect to management of the harp seal herd in order that such a population size can be achieved.

Government response

The Government accepts the Committee's recommendation to establish a panel of eminent persons to provide advice on a long-term strategy for the management of seal populations. The panel will report to the Minister of Fisheries and Oceans. It is initially expected that the panel will be asked to consider the Committee's findings and report by the fall of 2000 so that their advice can be considered in the development of the seals management plan for 2001.

Eminent Panel on Seal Management

Panel Members

Chair
Dr. Ian McLaren
Professor Emeritus
Biology Department
Dalhousie University
Halifax, NS B3H 4J1

Members
Mr. David Vardy
Channing Fellow
Office of the President
Public Policy Research Centre
Queen's College, Room 4008
Memorial University of Newoundland
St. John's, NF A1A 5B2

Professor John Harwood
NERC Sea Mammal Research Unit
Gatty Marine Laboratory
University of St. Andrews
St. Andrews, Fife Ky16 8LB
UK

Dr. Solange Brault
Associate Professor
Department of Biology
University of Massachusetts Boston
Boston, Mass. 02125
USA

APPENDIX 2

Panel meetings and contacts

1. Initial Meetings

The Panel met unofficially on two occasions before the beginning of their contract in June 2000. Dates, places and people with whom the members met are listed below. Affliliations and postions are noted as appropriate.

9-10 May 2000, Halifax NS (Panel)
- Dalhousie University
  - Bob Brown
  - Jeff Hutchings
  - Sarah Iverson
  - Warwick Kimmins
  - Ian McAllister
  - Ransom Myers
  - Chris Taggart
  - Hal Whitehead

- DFO/Bedford Institute of Oceanography (BIO)
  - Don Bowen
  - Paul Fanning
  - Bob Mohn

- David Sergeant (retired DFO seal biologist)

11-13 May 2000, St. John's NF (Panel)
- DFO/Northwest Atlantic Fisheries Centre
  - Bruce Atkinson (Regional Director, Science Oceans and Environment)
  - John Anderson
  - Mike Hammill (IML)
  - Peter Shelton
  - Becky Sjare
  - Garry Stenson

- Memorial University of Newfoundland (MUN)
  - Leslie Harris (former President, MUN)
  - Jon Lien
  - Bill Montevecchi

2. Panel Meetings June 2000 - July 2001

21-26 June, Halifax NS (Panel)

Fisheries Resource Conservation Council
- Fred Woodman, Chairman
- Michel Vermette, Executive Director
- Maureen Yeadon

Dalhousie University
- Bob Brown
- Jeff Hutchings
- Sarah Iverson
- Ram Myers
- Chris Taggart

DFO/Bedford Institute of Oceanography (BIO)
- Don Bowen
- Paul Fanning
- Bob Mohn

19-22 July 2000, St. John's NF (McLaren, Vardy, Brault)

DFO/Northwest Atlantic Fisheries Centre
- Jim Carscadden
- David Kulka
- David Orr
- David Reddin
- Garry Stenson

Newfoundland Department of Fisheries and Aquaculture
- Hon. John Efford, Minister
- Frank Pinhorn
- Jerry Ward
- Other staff members

Memorial University of Newfoundland
- Stephen Carr
- Jon Lien
- Dawn Marshall
- Bill Montevecchi
- George Rose
- Joseph Wroblewski

Fisheries Association of Newfoundland and Labrador
- Alastair O'Rielly, President

Barry Group Inc.
  Karl Sullivan, VP Corporate Planning

Fish, Food and Allied Workers/CAW
  Earle McCurdy, President
  David Decker

Canadian Sealers Association
  Tina Fagan, Executive Director
  Bruce Parsons, Carino Co.
  John Kearley, Carino Co.
  Seans Clowe, Atlantic Marine Products Inc.

  David Wells, Caboto Fisheries
  Ken Budden, Fogo Coop

Canadian Centre for Fisheries Innovation
  Glenn Blackwood, Managing Director
  Cathie Horan

Bonavista Bay fishermen, including:
  Lou and Don Fennell, Plate Cove West
  Marlin, Bernice and Brad Quinton, Open Hall
  Bill Maloney, Duntara
  Horace Newell
  Hedley Butler
  Dave White

Atlantic Marine plant, Catalina, NF
  Alan Bragg

11-12 September 2000, Ottawa ON (Panel)

Department of Fisheries and Oceans
  Hon. Herb Dhaliwal, Minister
  David Bevan
  Pat Chamut
  John Davis
  Darlene Elie
  Liseanne Forand
  Stephen Hogue
  Ken Jones
  Grace Mellano
  Howard Powles
  Jake Rice
  Scott Tessier

International Fund for Animal Welfare
    Rick Smith, National Director, IFAW Canada
    Lea-Ann Mallett, Deputy Director, IFAW Canada
    David Lavigne, Science Advisor, IFAW International

13 September 2000, Mont Joli, Québec (Panel)
DFO/Institut Maurice-Lamontagne (IML)
    Jean Boulva (Regional Director, Science Oceans and Environment)
    Martin Castonguay
    Denis Chabot
    Yves Dubé
    Alain Fréchet
    Jacques A. Gagné
    Jean François Gosselin
    Mike Hammill
    Yvan Lambert
    Ian McQuinn
    Bernard Morin
    Yvan Simard

15 September 2000, Halifax NS (Panel)
NS Department of Fisheries & Aquaculture
    David Hansen, Director
    Gary Scott, head, NS seal committee

Scotia-Fundy Mobile Gear Association
    Brian Giroux, Executive Director

Eastern Fishermen's Federation
    Melanie Sonnenberg, Co-ordinator (NB)
    Norma Richardson (NS)
    Buck Watts (PEI)

South West Nova Fish Packers' Association
    Bob Covert
    Doug Garrison

Ecology Action Centre
    Mark Butler, Marine Issues Coordinator
    Lara Gibson

Dalhousie University
    Martin Willison (also as President, NS Naturalists)

8-11 January 2001, Halifax NS (Panel)
The major purpose of this meeting was to work on the interim report, but the Panel also met with:

DFO/Bedford Institute of Oceanography (BIO)
- Don Bowen
- Paul Fanning
- Bob Mohn

29-30 January 2001, St. John's NF (Panel)
DFO/Northwest Atlantic Fisheries Centre
- Alida Bundy (BIO)
- Scott Campbell
- Jim Carscadden
- Geoff Evans
- Paul Fanning (BIO)
- Brian Healey
- Mike Hammill (IML)
- George Lilly
- Bob Mohn (BIO)
- Fran Mowbray
- George Rose (MUN)
- Peter Shelton
- Becky Sjare
- Garry Stenson
- Doug Swain (DFO, Maritimes Region)

Fred Woodman (Chair, FRCC)

20-21 March 2001, Nuuk, Greenland (Brault)
Dr. Brault attended international meeting: "Seals in the Marine Ecosystem."

18 April 2001, Charlottetown PEI (McLaren)
- D. MacEwan, PEI Department of Fisheries and Aquaculture
- F. Bearirsto, PEI Fishermen's Association

30 April—2 May 2001, St. John's NF (Panel)
Newfoundland Department of Fisheries and Aquaculture
- Hon. Gerald Reid, Minister
- Brian Delaney
- Tom Dooley
- Mike Handrigan
- David Lewis
- Mark Rumboldt
- Mike Samson
- Mike Warren
- George Winters

Canadian Sealers' Association & the Sealing Industry Development Council
    Tina Fagan, Executive Director/Chairperson

Salmonid Association of Eastern Newfoundland
    Rick Maddigan, Director

Fisheries Resource Conservation Council
    Fred Woodman, Chair
    Bill Broderick
    George Rose (MUN)

International Fund for Animal Welfare
    Rick Smith, National Director, IFAW Canada
    David Lavigne, Science Advisor, IFAW International

Fisheries Association of Newfoundland and Labrador
    Alastair O'Rielly, President

Fish, Food and Allied Workers/CAW
    Earle McCurdy, President

DFO/Northwest Atlantic Fisheries Centre
    Garry Stenson

9-11 June 2001, Halifax NS (Panel)
DFO/Bedford Institute of Oceanography (BIO)
    Don Bowen
    Paul Fanning
    Bob Mohn

13-18 July 2001, St. Andrews, Scotland (Panel)
Panel met to work on the final report.

3. Additional contacts

Individual members of the Panel consulted frequently in person or by e-mail, phone or regular post with a wide range of people in the community, including many of those who met with the Panel as a whole. Below are listed (in alphabetical order) only those people whose names do not appear above. The list does not include DFO personnel.

Ray Andrews
Andrews Port Services Limited
Fisheries Advisor to Government of Nunavut

Roland Andrews
Staff Officer
Aboriginal Fisheries & Marine Mammals
DFO

Robert Comerford
Atlantic Canada Opportunities Agency
St. John's NF

Larry Felt
Department of Psychology
Memorial University of Newfoundland &
Salmonid Association of Eastern Newfoundland

Nell Halse - General Manager
New Brunswick Salmon Growers Association
226 Limekiln Road
Letang NB E5C 2A8

Mike Howley
Account Manager
Atlantic Canada Opportunitites Agency
St. John's NF

Dennis Ivany
Fish Harvester
Petley
Random Island, NF

Jack Marsh
Fish Harvester and Seal Collector
Lower Lance Cove
Random Island, NF

Gordon Munro
University of British Columbia
Vancouver

Knut Nygaard
Manager
Carino
G. C. Reiber

Jack Peddle
Seal collector

Mark Small
Sealer
Baie Verte, NF

Anthony Sinclair
University of British Columbia
Vancouver, B.C.

Ian Stirling
Canadian Wildlife Service
Edmonton, Aberta

Andrew Trites
University of British Columbia
Vancouver, B.C.

Jack Troke
Sealer
Twillingate, NF

APPENDIX 3

Public Input

The Panel sought public input through a number of other channels, including newspaper advertisements and letters to national and regional organizations.

1. Newspaper advertisements

Advertisements were placed in the *Globe and Mail* and *La Presse* on 18 October 2000.

a) *Globe and Mail*, Toronto

PUBLIC NOTICE

PANEL ON SEAL MANAGEMENT
The panel of independent experts formed by the Minister of Fisheries and Oceans to provide advice on a long-term strategy for the management of seal populations in Atlantic Canada invites input from stakeholders and interested parties. Final date for submissions is 17 November 2000.

Copies of the terms of reference, along with specific questions on which the panel is seeking input, are available from June Hall, Administrative Secretary, Seals Panel, c/- Biology Department, Dalhousie University, Halifax, NS B3H 4J1; Fax: (902) 494-3736.

b) *La Presse*, Montreal

AVIS PUBLIC

GROUPE D'EXPERTS SUR LA GESTION DES PHOQUES
Le groupe d'experts indépendants formé par le ministre des Pêches et des Océans pour formuler des avis sur une stratégie de gestion à long terme des populations de phoque de l'Atlantique canadienne invite les intervenants et les parties intéressées à présenter leurs commentaires d'ici au 24 novembre 2000.

Pour obtenir des copies du cadre de référence et un aperçu des sujets sur lesquels le groupe aimerait avoir des commentaires, veuillez communiquer avec June Hall, secrétaire administrative, Groupe d'experts sur la gestion des phoques, Département de biologie, Université Dalhousie, Halifax, Nouvelle-Écosse, B3H 4J1; fax : (902) 494-3736.

2. Letters to organizations

a) The following letter was sent to a number of organizations during August 2000.

Dear XXX:

As Chair of a Panel on Seal Management, established in June this year by the federal Minister of Fisheries and Oceans, I am writing to ask if your organization could assist us in our task.. We particularly need concrete criticisms of and suggestions for improvements in existing policies, information, and analyses pertinent to seal management. We have not been asked to address "moral" or humane issues, however important these may be.

In the broadest sense, the use of marine resources under Canada's Oceans Management Strategy under our Oceans Act, is stated to be "based on the principles of: a) sustainable development, that is, development that meets the needs of the present without compromising the ability of future generations to meet their own needs; b) the integrated management of activities in estuaries, coastal waters and marine waters that form part of Canada or in which Canada has sovereign rights under international law; and c) the precautionary approach, that is, erring on the side of caution." Management goals for Canadian Harp Seal populations are explicitly given in DFO's Seal Management Plan for 1999 as supporting: "a) a market-driven commercial hunt within conservation parameters; b) full use of each animal hunted; and c) humane hunting practises." The 2000 Seal Management Plan states that, "since 1987 the seal hunt has been managed on a long-term, sustainable basis [in which] replacement yield has been used as a benchmark for sustainability." Replacement yield is "the number of animals that can be taken in a given year without reducing the total population in the next year."

To assist in your considerations, we attach the Terms of Reference given to the Seal Panel, along with a questionnaire on matters that are of importance to the panel, although this is not intended to restrict your response.

The panel has to date had meetings, largely with scientists and some "stakeholders," in Newfoundland and in Halifax, NS. The panel will be in Ottawa 11-13 September, and would be pleased to meet then with representatives of your organization. For consideration of possible times and places for such a meeting, please contact me at the above postal address, phone number, or e-mail address.

Yours sincerely,
Ian A. McLaren

b) The following letter was sent to a number of stakeholders in early April 2001.

Dear XXX

The independent Panel on Seal Management, appointed last year by the Federal Minister of Fisheries and Oceans, will complete its work and submit its final report later this spring. The Terms of Reference of the Panel state that it "will base its work primarily on review of available reports, information, and surveys, but "may wish to consult parties for information directly related to their objectives." The Panel has indeed solicited and obtained such consultations, both through direct contact with interested parties and by newspaper advertisements in October 2000. By this letter the panel offers a last opportunity for input by stakeholders with a direct interest in the issues.

The Panel would appreciate receiving any further reports, briefs, or letters containing knowledge, understanding, or perceptions about seal populations, their possible impacts on fish and fisheries, and possible management strategies. On the last aspect, we are particularly interested in practical suggestions, on how proposed management options might be implemented. Because of time constraints, the Panel would appreciate having any further written input before the end of April, and in any case cannot consider material received after May 10.

The Panel will hold its last discussions in St. John's Newfoundland, beginning April 30. During that visit the dates of April 30 and May 1 will be kept open for last meetings with individuals, representatives, or groups receiving this letter of invitation, should they so wish.

We realize that this is rather short notice, but believe that those receiving this letter of invitation are already aware of the Panel's existence and mandate, and some have already supplied with valuable input.

If interested, please respond to June Hall, the Panel secretary, at the addresses below with either written material or to arrange times of meeting with the Panel in St. John's within the period April 30 – May 1.

Yours sincerely

Ian A. McLaren
Chair
Seal Panel

3. Questionnaire on Seal Management in Atlantic Canada

The following questionnaire was provided to those who responded to the advertisement, and appended to letters. The questions are based on issues raised by the Terms of Reference.

1. What do you think of current objectives of management of seal populations in Atlantic Canada?

2. What do you think the objectives of seal management in Atlantic Canada should be?

3. Given the existing objectives or your proposed ones, is there an optimum level of abundance for seal populations? If not, what criteria should be used to define this optimum? For example:
    a) should the extent of predation by seals on commercial fish species or species that sustain commercial fish stocks be used as a criterion in setting an optimum?
    b) should maximizing economic benefits be used as a criterion in setting an optimum population for seals?
    c) what other criteria might be used?

4. If the optimum calls for a reduction in numbers of seals, beyond those killed under present management policies, what management approaches can be used to reach such a population level? For example:
    a) killing of young seals?
    b) killing of older seals?
    c) sterilization of females?
    d) other approaches?

5. What do you know of current research on seal populations that is used for management of their populations? What would be useful and/or necessary for future management?

6. It has been suggested by some that seals may be responsible for preventing or retarding recovery of certain greatly depleted commercial fish stocks. Do you know of evidence supporting or refuting such suggestions?

7. Where there is evidence that seal predation or gear damage negatively impacts fish populations, or aquaculture in localized areas, how is this best dealt with? For example:
    a) scaring of seals by whatever means proves effective?
    b) removal of regulations protecting seals to permit localized killing of such seals?
    c) organized local killing of seals by paid hunters?
    d) other means?

8. Are you aware of policies or management practices, or both, that are in effect in other countries that might be appropriate for seals in Atlantic Canada? Could you describe these?

4. List of submissions to the Panel

Below is a list of letters and submissions to the Panel, arranged by date and showing size and type of submission (letter, e-mail), title (if present), and author's address (where given). The list distinguishes between briefs written specifically for the Panel, and documents produced originally for other purposes. Many documents of the latter type were received during the Panel's mandate, and some are referred to in the report.

All letters and briefs are lodged with the Department of Fisheries and Oceans, Ottawa.

12 June 2000 (1 p. letter + docs.)
Michel G. Vermette, Executive Director
Fisheries Conservation Council
P.O. Box 2001
Station D
Ottawa ON K1P 5W3

6 June 2000 (2 pp. letter + docs.)
D.M. Lavigne, PhD
Science Advisor
International Fund for Animal Welfare

4 August 2000 (1 p. letter + 47 pp. brief0
Legislative reform: the basis of enhanced marine mammal management in Canada
M.L. Campbell and V.G. Thomas
Department of Zoology
Unversity of Guelph
Guelph, ON N1G 2W1

15 August 2000 (2 pp. letter + docs.)
Rick Smith, Ph.D.
National Director
IFAW Canada
1101-1 Nicholas St.
Ottawa, ON K1N

31 August 2000 (3 pp. letter)
Fred Woodman, Chairman
Fisheries Resource Conservation Council
P.O. Box 2001
Station D
Ottawa, ON K1P 5W3

19 September 2000 (1 p. letter)
Melanie Sonnenburg
Eastern Fishermen's Federation

P.O. Box 907
Grand Manan, NB E5G 4M1

21 September 2000 (2 pp. letter)
Peter Tabuns, Executive Director
Greenpeace
1726 Commercial Drive
Vancouver, BC V5N 4A3

22 September 2000 (2 pp. letter + doc.)
Allan R. Stein
Department of Chemistry
Memorial University of Newfoundland
St. John's, NF A1B 3X7

6 October 2000 (1 p. letter + 8 pp. brief)
Andrew Plumbly, Director
Global Action Network
1254 Mackay #1
Montreal, QC H3G 2H4

11 October 2000 (1 p. letter)
Peter Stoffer, M.P.
Rm 368, Confederation Bldg.
House of Commons
Ottawa, ON K1A 0A6

14 October 2000 (2 pp. letter)
Dr. Richard Alan, DVM, and Gloria Grow
Fondation Fauna Foundation
P.O. Box 33
Chambly, QC J3L 4B1

20 October 2000 (1 p. letter + 3 pp. report. Faxed.)
Nutrition of Young Inuit
Robert W. Spence, P. Eng.
Executive Director
The Association of Professional Engineers, Geologists and Geophysicists of the Northwest Territories (NAPEGG)
5, 4807–49th Street
Yellowknife, NT X1A 3T5

24 October 2000 (2 pp. e-mail)
Dominique Leiba
3910 Berne Street

Brossard , QC J4Z 2P2

24 October 2000 (3 pp. e-mail)
Michael Alvarez-Toye, candidate for the Green Party, Calgary Centre
Spokesperson, Calgary Animal Rights Coalition
41 6A, AB T2E 4A2

29 October 2000 (3 pp., sent as letter and e-mail)
Jennifer Surrette
6246 Yukon St.
Halifax, NS B3L 1G1

1 November 2000 (1 p. fax + 9 pp. brief)
Joint submission to the Eminent Panel on Seal Management from:
Environment Voters
Animal Alliance of Canada
Animal Protection Institute
Canadian Alliance for Furbearing Animals
Humane Society of the United States
Prepared by:
Liz White
Environment Voters
221 Broadview Avenue, Suite 101
Toronto, ON M4M 2G3
and
Barry Kent MacKay
International Wildlife Director
Animal Protection Institute (Canada)
31 Colonel Butler Dr.
Markham, ON L3P 6B6

8 November 2000 (1 p. e-mail + doc.)
Monte Hummel, President
World Wildlife Fund Canada
245 Eglinton Ave. E., Ste. 410
Toronto, ON M4P 3B7

11 November 2000 (1 p. e-mail)
a concerned citizen
[e-mail from Lisa Tartaglia]

13 November 2000 (3 pp. letter)
Debra Probert, Executive Director
Vancouver Humane Society
303-8623 Granville St.
Vancouver, BC V6P 5A1

15 November 2000 (1 p. letter + doc.)
Patricia Gray
11 Marjorie Crescent
Charlottetown, PE C1A 7V1

21 November 2000 (4 pp. e-mail)
Peter Haddow, Chairman
Seal Conservation Society
25 Lerwick Road
Aberdeen,
UK AB16 6RF

23 November 2000 (4 pp. e-mail)
Anthropocentrism and Theoretical Fatalism: A Comment on the Terms of Reference of the "Eminent Panel on Seal Management"
David Orton
Co-ordinator of the Green Web
R.R.#3
Saltsprings, NS B0K 1P0

24 November 2000 (3 pp. e-mail)
Response of Sea Shepherd Conservation Society to Questionnaire on Seal Management in Atlantic Canada
Andrew Christie
Sea Shepherd International
P.O. Box 2616
Friday Harbor, WA 98250
USA

25 November 2000 (1 p. letter)
C.M.M. Iles-Wright
143 Caswell Close
Farnborough
Hants
UK GU14 8TG

18 December 2000 (5 pp. letter + audio material)
Janet Russell
Tors Cove, NF A0A 4A0

10 January 2001 (1 pp. e-mail)
Lorne Salter, MA U of T (Criminology)
Markham, ON

23 January 2001 (1 p. e-mail)

Brian Pike

31 January 2001 (1 p. letter + doc.)
D.M. Lavigne, PhD
Science Advisor
International Fund for Animal Welfare

5 March 2001 (short e-mail)
Paul Whalen
member of Sea Shepherd Society

11 April 2001 (3 pp. letter)
Rick Smith, Ph.D.
National Director
IFAW Canada
1101-1 Nicholas St.
Ottawa, ON K1N

30 April 2001 (22 pp. Brief)
Seals – Sustainable Harvesting: Future Quotas
The Canadian Sealers Association
and the
Seal Industry Development Council
St. John's, NF

30 April 2001 (8 pp. brief)
Seals and Salmonids
Salmonid Association of Eastern Newfoundland (SAEN)
P.O. Box 29122
St. John's, NF A1A 5B5

May 2001 (18 pp. brief)
The Newfoundland and Labrador Seal Fishery: Where do we go from here?
Fish, Food and Allied Workers (FFAW/CAW)
St. John's, NF

8 May 2001 (short e-mail)
Paul Lamoureux, Coordonnateur
Table Filière Loup-marin Inc.
Cap-aux-Meules, Québec

14 May 2001 (1 p. letter + 2 pp. brief, faxed)
Mervyn Anderson
Labrador Inuit Association
P.O. Box 70
Nain, NF A0P 1L0

17 May 2001 (short e-mail)
Nell Halse - General Manager
New Brunswick Salmon Growers Association
226 Limekiln Road
Letang NB E5C 2A8

31 May 2001 (4 pp. letter)
Fred Woodman
Fisheries Resource Conservation Council
P.O. Box 2001
Station D
Ottawa, ON K1P 5W3

7 June 2001 (1 p. letter + 27 pp. brief)
Seals – Sustainable Harvest of a Renewable Resource
Department of Fisheries and Aquaculture
Government of Newfoundland and Labrador
P.O. Box 8700
St. John's, NF A1B 4J6

APPENDIX 4

Methods used for calculating the effects of different management Scenarios on consumption of groundfish by harp seals

This Appendix details the methods used for calculating the effects of different management scenarios on consumption of groundfish by harp seals, presented in section **5.2**.

For all calculations we used the most current estimates from Healey and Stenson (submitted) for pup abundance and mortality rate, as well as those provided to us by Dr. G. Stenson DFO (DFO, pers. com., March-April 2001), on seal residency in the nearshore and offshore waters by season, proportion of different fish species in seal diets, and the variances associated with these.

Values for **Figure 5.1**, representing potential changes in consumption of five fish species groups in NAFO Division 2J3KL due to a 3% annual increase in harp seal numbers, are given in **Table A.4.1**. These calculations are initialized with the estimated numbers of seals by age class (0 to 13+ yrs) for year 2000, themselves resulting from the fitting procedure described in Healy and Stenson (2000). The numbers at age are projected over 10 years with a growth factor of 1.03; the variance in total abundance in year 2000 estimated by Healy and Stenson (2000) is used throughout the projection. Diet data used were the mean proportions of relevant species found in all stomach samples and their associated variance, in each season (Winter, Spring) and each area (nearshore, offshore). These were combined with mean proportions (and their variances) of time spent by harp seals in Division 2J3KL, again by season and area.

In **Figure 5.2** only cod consumption is considered, under a set of five management scenarios; the values used for graphing are given in the "COD" row of **Table A.4.2**. To estimate the decrease in fish consumed due to a given scenario, the age-structured (0 to 13+ age classes) harp seal population is first projected over ten years with the increased mortality or decreased fertility caused by management action. An annual mortality of m = 0.0599 for 1+ age groups and of 3m for 0-age group, and fertility rates for age classes 4, 5, 6, 7, and 8+ years of .0423, .0934, .1712, .3168 and .3462 respectively, were applied to the number at age in year 2000; these estimated rates are from Healey and Stenson (submitted). In the scenarios, the following management actions are taken:

- The Total Allowable Catch of pups (effectively 0-yr class individuals) is of **750,000** per year for one year only, and zero thereafter; the whole TAC is taken each year.
- The Total Allowable Catch of pups is of **150,000** per year for the first 5 years (i.e. same total catch as previous scenario), and zero thereafter.
- A cull of adult females of **150,000** per year in done for five years; the cull age structure is identical to the population age structure, that is there is no age preference.
- A cull of adult females of **75,000** per year in done for five years (i.e. half of previous scenario).
- No cull is done; **150,000** females are sterilized each year for five years. Sterilization is assumed 100% effective for the rest of females' lives.

The same procedure as for the 3% seal increase is then used to estimate fish consumption and associated variances.

In **Figure 5.3** a single management scenario is considered – increasing the pup TAC by 150,000 for 5 years – and its effect on different species groups of fish is considered. The complete sets of numbers for other scenarios (minus sterilization) are given in Table A.4.2 for reference.

Because no estimates of variance were obtained from the fitting procedure of Healy and Stenson (2000), seal population changes were calculated directly; in reality large uncertainties about mortality and fertility rates will exist, and will contribute to substantial increases in the variance in fish consumption.

Table A4.1 Potential increase in consumption of five fish species or groups due to a 3% annual increase in harp seal numbers.

	Year										CV
	1	2	3	4	5	6	7	8	9	10	
Atlantic Cod	0	1,104	2,241	3,413	4,619	5,862	7,142	8,461	9,818	11,217	0.369
Capelin	0	4,890	9,927	15,115	20,459	25,962	31,631	37,471	43,485	49,679	0.163
Greenland Halibut	0	2,178	4,421	6,731	9,110	11,561	14,086	16,686	19,364	22,123	0.346
American Plaice	0	6,609	13,415	20,426	27,648	35,086	42,747	50,638	58,766	67,137	0.531
Pleuronectidae	0	15,239	30,935	47,103	63,755	80,907	98,573	116,769	135,511	154,816	0.309

Table A4.2 Reduction in fish consumption (Tonnes) by seals due to management action (Comparison of Table scenarios)

	YEAR										CV
	1	2	3	4	5	6	7	8	9	10	
COD											0.3
1-Yr pup TAC incr by 750,000	3904	3,904	4,024	3,886	3,626	3,512	3,543	3,863	4,452	5,035	
5-Yr pup TAC incr by 150,000 each year	789	1,570	2,374	3,152	3,877	3,791	3,718	3,686	3,799	4,081	
5-Yr Adult Female Cull, 150,000 each yr	1,149	2,198	3,407	4,758	6,182	7,282	8,318	9,305	10,320	11,311	
5-Yr Adult Female Cull, 75,000 each yr	575	1,099	1,703	2,379	3,091	3,641	4,159	4,653	5,160	5,656	
5-Yr Adult Female Sterilization, 150,000 each yr	0	509	1,267	2,252	3,398	4,636	5,812	6,937	8,086	9,390	
CAPELIN											0.1
1-Yr pup TAC incr by 750,000	95,816	94,825	97,754	94,407	88,092	85,317	86,070	93,832	108,155	122,320	
5-Yr pup TAC incr by 150,000 each year	19,163	38,128	57,679	76,560	94,179	92,079	90,328	89,544	92,293	99,139	
5-Yr Adult Female Cull, 150,000 each yr	27,922	53,401	82,756	115,575	150,179	176,895	202,070	226,042	250,693	274,775	
5-Yr Adult Female Cull, 75,000 each yr	13,961	26,701	41,378	57,788	75,089	88,447	101,035	113,021	125,346	137,388	
GREENLAND HALIBUT											0.3
1-Yr pup TAC incr by 750,000	10,346	10,239	10,555	10,194	9,512	9,212	9,294	10,132	11,678	13,208	
5-Yr pup TAC incr by 150,000 each year	2,069	4,117	6,228	8,267	10,169	9,943	9,753	9,669	9,966	10,705	
5-Yr Adult Female Cull, 150,000 each yr	3,015	5,766	8,936	12,480	16,216	19,101	21,819	24,408	27,069	29,670	
5-Yr Adult Female Cull, 75,000 each yr	1,507	2,883	4,468	6,240	8,108	9,550	10,910	12,204	13,535	14,835	
AMERICAN PLAICE											0.5
1-Yr pup TAC incr by 750,000	31,398	31,073	32,033	30,936	28,867	27,957	28,204	30,748	35,441	40,083	
5-Yr pup TAC incr by 150,000 each year	6,280	12,494	18,901	25,088	30,861	30,173	29,599	29,342	30,243	32,487	
5-Yr Adult Female Cull, 150,000 each yr	9,150	17,499	27,118	37,873	49,212	57,966	66,216	74,071	82,149	90,040	
5-Yr Adult Female Cull, 75,000 each yr	4,575	8,749	13,559	18,936	24,606	28,983	33,108	37,036	41,074	45,020	
PLEURONECTIDAE											0.2
1-Yr pup TAC incr by 750,000	72,402	153,493	243,525	341,215	442,362	520,756	591,820	659,340	729,886	803,005	
5-Yr pup TAC incr by 150,000 each year	14,480	26,359	37,525	48,023	57,892	53,107	51,160	50,719	52,723	56,963	
5-Yr Adult Female Cull, 150,000 each yr	14,480	30,699	48,705	68,243	88,472	104,151	118,364	131,868	145,977	160,601	
5-Yr Adult Female Cull, 75,000 each yr	142,808	258,320	386,071	520,798	658,133	747,606	832,849	917,883	1,012,138	1,112,123	

APPENDIX 5

Letter to Panel Chair from Panel Member David Vardy

Dr. Ian McLaren
Chair
Seal Panel
Halifax

Dear Dr. McLaren

I am writing this letter to advise you as to how I believe the impact of seal predation should be characterized in our Report. It is my view that seal predation has been having a serious impact upon commercially exploited fish stocks, particularly depressed groundfish stocks. In the event that there may not be a consensus of the Panel upon the nature and characterization of this impact I have a responsibility to make this conclusion known to Members of the Panel and to the Minister of Fisheries and Oceans.

In its assessment the Panel has to bring to bear the professional expertise and judgment of its members with respect to the evidence placed before it. This evidence comes to us from a number of sources, including published reports from scientists as well as reports from fish harvesters, from industry and from other interested parties. Our task is to place the appropriate weight on this evidence, bearing in mind the terms of reference of the Panel. The evidence we have assessed, particularly with respect to seal diets, contains a high level of uncertainty and ambiguity. However, our role as a Panel is to give our best advice on the overall balance of the evidence.

My decision to present this dissenting view has been reached only after considerable reflection. I am not a scientist. Nevertheless, my professional career has required me to take management decisions and to make recommendations to governments based upon the assessment of evidence and analysis developed by a broad range of disciplines. The credibility of my judgment rests upon my experience as a policy advisor to governments, as an economist, as the head of a fisheries and marine institute, as chair of a quasi-judicial hearings tribunal and as Deputy Minister of Fisheries for the Province of Newfoundland and Labrador. My professional involvement with the fishery and people in the fishery covers a span of close to 40 years.

It is incumbent upon each Panel Member to weigh the evidence and reach his or her own independent conclusions. Each is accountable for the conclusions and advice we render to the Minister and each of us recognizes the gravity of this weighty responsibility.

In presenting my opinion I do so with the greatest respect for, and deference to, the other Members of the Panel, Drs. Solange Brault, John Harwood, and Ian McLaren, the Chair. These Panel Members are recognized internationally for their outstanding scientific credentials and for their high standard of professional integrity.

The evidence is that harp, hooded and grey seals take a large number of cod and that this consumption is a major component of the high level of cod mortality that has been recorded. No survey of hooded seals has been conducted since 1990 and the Panel does not have the evidence required to assess the size of the herd and whether it has been growing. Hooded seal diet information recently compiled at the request of the Panel suggests that hooded seals could be a larger predator on cod than had been previously believed.

Harp seals are by far the largest component of the Atlantic seal population. Current survey information exists for harp seals and the size of the herd is estimated to be 5.2 million animals, up from about two million in the early 1970s and from more than four million in the early 1990s. This is the highest level reached by this herd in recent history since estimates have been available (2001 Management Plan, DFO). Consumption by harp seals is the largest component of seal predation. The total allowable catch (TAC) is established with reference to the best scientific advice on the replacement yield. If the replacement yield is not taken it is likely that the harp seal herd will continue to grow, as will seal predation upon commercially important stocks. Over the past twenty years there were few years when the harvest came close to taking the TAC. For the current year, the catch is estimated to be 210,000 animals, from a TAC of 275,000.

The total prey taken by seals in Atlantic Canada was estimated for 1996 to be in excess of four million tonnes (Hammill and Stenson, 2000), with over three million tonnes of fish species and just below one million tonnes of invertebrates. Capelin was estimated to be the main prey component, followed by sand lance, Pleuronectidae (various flatfish species), Greenland halibut, Atlantic cod, Arctic cod and redfish. Capelin was estimated at over one million tonnes. These estimates by Hammill and Stenson, in their 2000 paper, have since been subject to revisions, many of which are described in our Report, particularly those relating to Atlantic cod.

The Panel has examined the impact of seal predation on many of the major commercial stocks in Atlantic Canada. With the limited time and resources available to it the Panel has not been able to examine in detail every commercially important stock. Its examination of the evidence has been directed toward selected groundfish stocks, which are highly vulnerable to mortality, particularly Atlantic cod. The lack of recovery of Northern cod in 2J3KL has been well documented and poses a serious fisheries management challenge. It is not the mandate of the Panel to prescribe a recovery plan for Northern cod or for other distressed cod stocks in Atlantic Canada. However, I do believe that it is within our mandate to provide an opinion as to whether seal predation represents a serious problem for recovery and rebuilding of these stocks.

Sampling of seal stomachs, along with other techniques for evaluating consumption of seal prey, reveals that Atlantic cod is not a major food source for seals. In relationship to capelin and Arctic cod, Atlantic cod is a small diet component in most of the samples. However, even though Atlantic cod has been a relatively small component of seal diets the amounts consumed are large relative to the small size of the remaining cod biomass. There seems also to be a tendency of late for harp seals to consume larger cod. Mortality due to seal predation has therefore to be seen as a threat to the recovery of major stocks of Atlantic cod, whose resilience has been impaired through the sharp decline in the size of the stocks and the disappearance of large spawners. A large part of the remnant of the Northern cod biomass is gathered in a few localities where they may be vulnerable to predation. Uncertainty about the availability of capelin as a food for distressed cod stocks is also a concern, in the context of substantial seal predation upon capelin. These factors constitute a large part of the evidentiary base for the judgments I have formed.

Atlantic cod, comprised of a number of identified stocks found in various NAFO Divisions and sub-Divisions, has been the subject of the most detailed examination by the Panel. The evidence of seal predation on cod and other groundfish stocks contains considerable uncertainty and the Panel has presented recommendations for future research to help in the resolution of these uncertainties. The Panel has also presented management options for consideration by the Minister, including options designed to reduce mortality from seal predation on commercially important stocks. In presenting these options the Panel has been mindful of the need to apply sound conservation principles to the management of seal resources as well as to the management of commercial stocks of fish and shellfish.

It has proven to be difficult to arrive at a consensus on the gravity of the threat posed by seal predation and on how this should be characterized in the final Report of the Panel. This difficulty prompts me to write this letter to express a divergent opinion.

In the event that the majority of Panel Members cannot endorse the assessment set forth in this letter I am hereby requesting that you, as Chair of the Panel, include in the Report of the Panel to the Minister of Fisheries and Oceans the following statement. "In the case of Atlantic cod, to which the Panel has directed much of its attention, the evidence has led Panel Member David Vardy to the conclusion that seal predation is making such a large contribution to the high level of mortality as to delay or possibly prevent recovery. The low level to which the spawning biomass of Northern cod has been reduced, with virtually no recovery since the moratorium of 1992, combined with the loss of larger spawners from the stock, are factors that make this stock particularly vulnerable to seal predation. Seal predation poses a serious threat to the recovery of Northern cod and other important cod stocks in Atlantic Canada and to the rebuilding of these stocks to their historical levels. He has requested that this dissenting statement be inserted in the Final Report of the Panel of Eminent Persons to the Minister of Fisheries and Oceans for Canada and that this letter be appended to the Report."

With best wishes,

Yours sincerely,

David A Vardy [Original signed by David A. Vardy]

Panel Member

July 30, 2001